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PREFACE

That the nonscience student of today is interested in the physical world about him, and realizes the importance of scientific knowledge, need not be questioned The many orientation and survey courses offered in our colleges and universities bear witness to this fact It is doubtful, however, if the problem of introducing serious but nonprofessional science students to the field of physics has yet been adequately solved The author of the present text has come to feel that the answer does not lie so much in eliminating most of the technical parts of the subject as it does in divorcing the subject matter of physics as much as possible from *arithmetic*, for it is the *numerical* part of physics at which the nonscience student shudders with the usual comment that he never could "see" mathematics Furthermore, there is a surprising amount of material in a college physics course which need not be treated numerically Experience has shown the author that a one semester "nonarithmetical" course, without the omission of otherwise technical vocabulary, is not only possible but practicable for these students who will probably not go on in physics It has been found that a real appreciation of the subject, not to be confused with a false sense of comprehension can be developed in this manner

To be sure, the arithmetic may not be completely eliminated but it can be minimized almost to the vanishing point Of course this results in a corresponding sacrifice in the terseness and the rigor which properly characterize the general college physics course, but this need not be overdone Although the language of physics is, to a certain extent, the language of mathematics because the physicist appreciates this abbreviated and indispensable symbolic form of expression it does not follow that the student who lacks a mathematical bent cannot appreciate a large part of that fundamental science which plays such an important part in the world in which he lives Moreover, the physicist should feel an obligation to help his nonscientific colleague obtai

clearer picture of the world of physics and should be willing to forego the niceties of mathematical language when necessary Such a feeling has motivated the preparation of this book

In this text the order of development of the topics is a logical one designed to emphasize the unity of the subject matter The relationships between each topic and the ones preceding it are carefully indicated so that the entire subject is developed from fundamental considerations Technical vocabulary, however, is not avoided It is emphasized, to encourage correct usage of technical terms Every technical term is italicized and defined when it is first used Only the arithmetic is minimized It is the writer's opinion, based upon experience, that such a presentation can be made to interest the serious nonscience student without resort to the superlatives and the spectacular phases of pseudo science

It is definitely expected that a course based on this text will be a lecture course and that considerable attention will be given to lecture demonstrations Physics, unlike many subjects, lends itself to the lecture type of presentation because of the almost unlimited amount of demonstration equipment and visual-aid material which is available The lecturer will find innumerable opportunities to expand upon the material included in this text according to his available equipment These pages are not intended to replace the spoken word, but rather to serve as a guide for reading assignments and as an outline of subject matter

To facilitate the administration of such a course of one semester in length, the material is subdivided into chapters each of which may be considered roughly as a weekly assignment Questions are listed after each chapter and general review questions are inserted at places appropriate for hour quizzes The latter are of the "multiple choice" type, they can all be answered on the basis of this text, but they have intentionally been made difficult enough to require a genuine understanding of the points covered

The student is cautioned against rapid and careless reading of this text In the absence of arithmetic, words have to carry an extra burden, and they must be read carefully, even slowly, for their full meaning Time must be allowed for reflection

C E B

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CONTENTS

CHAPTER I

INTRODUCTION

SCIENTIFIC METHOD FUNDAMENTAL CONCEPTS, MEASUREMENTS AND BASIC UNITS

To many, the science of physics is a profound, highly math
matical, and exceedingly difficult subject to be undertaken l
those gifted with special mathematical abilities and to be avoid
by all others Although it is true that physics is probably tl
most highly organized branch of science today and does requi
profound mathematical analysis for its complete comprehensio
it is also true that it is so closely related to almost every activit
of everyday life that some familiarity with its laws and concep
should be had by every person who lays claim to being educate
Moreover, contrary to popular belief, a real insight into the natu
of the physical world can be obtained without the use of highl
mathematical language Naturally the professional physicist
unwilling if not unable, to dispense with such a useful tool
concise analytical expression as is afforded exclusively by math
matics, but the lay reader possessing a reasonable degree
scientific curiosity should not be deceived into thinking that tl
wonders of this fundamental science are forever denied him
with an ability to reason logically, he is but willing to undertak
the cultivation of a technical vocabulary Of course, this is not
trivial undertaking and will require concentration

Scope of Physics A brief consideration of such matters
force, work, motion, energy, fluid phenomena, waves, sound, hea
electricity, magnetism, radio, electrons, lenses, prisms, optic
instruments, color, and polarized light is, in general, the scope
this study These topics are to be considered, however, not as
series of unrelated things, but rather as a part of a single subje
—physics, the study of the physical world in which we live A
these topics are characterized by technical terms, and one of tl
purposes of this study is to develop a proper appreciation of

terms by learning their correct definitions as well as to acquire a familiarity with certain fundamental relationships which experience has shown to exist between them In this way only can an appreciation of physics be obtained, when account is taken of the high degree of organization that the science has achieved

Definition of Terms Most of the terms used in physics are defined terms that is to say, they take on their precise technical meaning merely because of common agreement. It will therefore be necessary at the very outset to recognize that the defining of new terms is not just a preliminary but is an indispensable condition for the success of our whole program It is perhaps not an exaggeration to say that an introduction to physics is largely a study of one concept after another, each of which is carefully defined in terms of concepts more fundamental than itself Thus a structure of related concepts is developed, based upon certain ones which are considered fundamental and incapable of definition in terms of anything more basic The full significance of this statement is not easily realized, but when the student finds that all the concepts of mechanics involve only three fundamental concepts—length, mass, and time—and that all the rest can be derived from these, he begins to appreciate the unity of physics A consideration of these three fundamental concepts is to be the first detailed study in this text, but before this is undertaken, several broad aspects of the situation will be considered

Inductive vs Deductive Reasoning The foregoing references to the logical development of this subject from fundamental considerations to more complex concepts may possibly convey the impression that physics exemplifies purely deductive reasoning On the other hand, the very expression 'scientific method' implies 'inductive reasoning" It should be pointed out, however, that inductive reasoning characterizes the research phases of a science After a body of information has been discovered and properly organized, it is often passed on most effectively to future generations of students by deductive processes Deductive reasoning was developed to a high degree by the Greek philosophers, but deductive reasoning alone was unable to advance the study of physics beyond certain limits False premises lead to wrong conclusions in spite of correct reasoning Thus Aristotle,[1] the famous Greek philosopher, reasoned that heavy

[1] See chapter II for historical summary of developments in physics

bodies fall faster than light ones, and this conclusion was actually accepted as true for hundreds of years simply because of the authority behind it It was not until the time of Galileo (1564–1642) that the matter was tested by experiment and found to be fal e Galileo is often called the father of experimental physics because he was one of the first to advocate the basing of conclusions upon experimental fact rather than upon deductive reason ing alone

The Scientific Method The scientific method, as initiated by Galileo is inductive and always involves the several following distinct steps In the first place *observations* are made Then a *hypothesis* is postulated in terms of which the observed facts are consistent A successful hypothesis becomes the basis of a theory which not only "explains" but suggests further observation in the form of *experimentation* Finally a successful theory leads to the establishment of a *scientific law* Thus the scientific method is based upon observation and inductive reasoning It was by such a procedure that the laws of motion of the heavenly bodies were 'discovered" Attention is called particularly to the role played by observation in the process Reasoning alone, no matter how correctly it is done, is not sufficient to establish a scientific law or principle Observable facts are facts regardless of the methods used to explain them Thus physics is essentially an experimental science, yet the student need not follow the same path as the pioneer in order to understand what the pioneer has accomplished In this text the student will not be required to discover' for himself

Nature of Explanations. A word regarding the nature of explanation is perhaps in order at this point An explanation of anything is always a relative matter It is the making of a thing seem reasonable to a person in terms of his past experiences Different degrees of appreciation have to be recognized, and what constitutes an explanation of something to an advanced student of a subject is likely to be quite unsatisfactory, if not unintelligible, to a beginner Thus, as already pointed out, mathematics is essential for the explanation of physical phenomena for the more advanced student of the science, but to the uninitiated explanations in terms of mathematics often become unsatisfactory To the beginner, such matters as vocabulary are more important than mathematical relationships, although some of

concepts are admittedly mathematical by their very nature Fortunately for this study, however, there is ample material for qualitative, or descriptive, considerations in elementary physics to enable the beginner to get a fairly good idea of the nature of the subject Although the explanations and definitions in this text appear verbose if compared with the standards of the professional physicist, they are nevertheless adequate for our present purpose

Quantitative Observations—Measurement. Since the scientific method not only calls for an ability to reason but also for careful observations, it is obvious that measurement plays an important role in physics Observations must be quantitative as well as qualitative Thus the question "how much" must always be answered before it is safe to base theoretical conclusions on any observation This does not mean that the present reader must concern himself unduly with arithmetical details, but it does mean that the experimental physicist must give as much attention to his tools, which are all forms of measuring instruments, as the theoretical physicist gives to the laws and processes of mathematical analysis and logic The distinction between experimental and theoretical (or mathematical) physicist is often made, but it is important to note that the theoretical physicist is limited to the material furnished by the experimentalist

Direct vs Indirect Measurements Measurements of all kinds have to be made, but a remarkable thing about physics is the fact that not all measurements have to be made directly In fact, many of the so-called measurements in physics, such as the determination of the size of an atom, or the measurement of the velocity of light, etc , are indirect measurements This again is the result of the high degree of organization of the subject The laws of physics and their relationships require that certain things must be so if certain other things are true Thus two simple measurements of length yield a value of the area of a rectangle Similarly, a measurement of length and one of time suffice to determine speed, to an accuracy comparable with that of the two measurements Furthermore, a determination of length, one of time, and one of mass enable the physicist to measure the kinetic energy of a body, or its momentum, or any one of many quantities to be defined later In brief, no more than these three kinds of direct measurement are required to determine any mechanical characteristic of a physical body This is merely another way of stating our

earlier assertion, viz , that all the concepts of mechanics are derived concepts expressible in terms of three fundamental ones length, mass, and time Thus we see that the direct measurements in physics, at least in the field of mechanics, can be restricted to measurements of these three fundamental things

Nature of Measurements If we stop to consider, we realize that a measurement, such as a measurement of length, for example, is nothing but a comparison with a standard, which itself is nothing but a unit determined by common agreement Thus a table is said to be three feet long merely because its length coincides exactly with that of a standard yardstick held along it Similarly, the length of a rug or a room, may be determined with respect to a yardstick, a foot rule, a measuring tape, or for that matter any convenient unit of length Therefore length is some thing which can be measured in terms of units, but which otherwise has no significance except as it constitutes a basic concept for the development of other concepts In other words, a basic concept such as length cannot be defined in terms of anything simpler, but a measurement of it can be made in terms of a standardized unit Similarly, mass and time are quantities which are measured by comparison with standard units of these quantities It should therefore be quite clear that the first task in the study of physics is to understand the manner of specification of the units in terms of which length, mass, and time are measured, for everything else seems to depend upon these units

Incidentally, it should be noted that it is only by custom that these three particular concepts are taken as basic for the development of the entire subject Theoretically any three concepts could have been used, but these three give the most natural, and probably the simplest, development

Without further delay we shall proceed to the specification of the generally accepted units of length, mass, and time, with the understanding that all the concepts of physics are to be expressible in terms of units, each of which will be related in some way to the units of these three quantities Complicating the situation somewhat, we find that agreement is not universal in these matters and that at least two independent systems of units must be considered, the so-called metric system and the English system of units

The English standard of length is the *yard*, • dis-

tance between two scratches on a certain bar carefully kept in London This length is subdivisible into three feet or thirty-six inches The working unit in this system is taken as the *foot* The metric standard of length is the *international meter*, defined as the distance between two scratches on a certain platinum iridium bar preserved near Paris, France Although this unit was originally intended to represent a certain fraction of the earth's circumference continued measurements of the latter quantity have disclosed errors in the original determination but this does not in any way affect the agreement by which this particular length is accepted as the standard Secondary standards, which are replicas of the original, are kept in every country The one for this country is preserved at the National Bureau of Standards in Washington, D C Incidentally the American standard of length is the American yard, which although approximately equal in length to the English yard, is legally defined as 3600/3937 of the international meter One one hundredth part of the meter is the *centimeter*, which has become the working standard of length in scientific work Thus the metric and English units of length are connected by the approximate relationship that one inch equals 2 54 centimeters This is worth remembering It is also worth noting that international commissions are constantly at work maintaining and improving the legal status of units for purposes of trade Indeed, a large portion of the program of the National Bureau of Standards is devoted to just such matters

Units of Mass To understand next how the unit of mass is defined, one must first be sure that the concept of mass is clear It is not such a familiar concept as length *Mass* is defined as a measure of inertia, where *inertia* is, by definition simply a certain property of matter, by virtue of which a body tends to resist any change in its motion The state of rest is considered a special case of motion, namely zero motion It will be pointed out later that a force is necessary to change the motion of a body, whence it follows that inertia is a property involving force and motion For the purpose of this discussion, however, a *force* is to be thought of simply as a push or a pull tending to change the motion of a body

Weight Not the Same as Mass One of the commonest forces to act upon a body is the pull of gravity, that is to say, the attraction of the earth All bodies on the earth are under such an influ

ence at all times The pull of gravity on a body is technically called its *weight* See fig 1 1 Thus a man is said to weigh 150 pounds because the earth attracts him with a force of 150 pounds This illustration also calls attention to the fact that the common and familiar unit of force is the *pound* In the metric system the unit of force is the *dyne*, roughly equivalent to the weight of a thousandth part of a postage stamp The pound is sometimes used as a unit of mass, a concept quite different from weight, and confusion arises from the use of the same unit to express two different concepts Such difficulty can be avoided only by painstaking care in the use of technical language See pp 37–38 for a more complete discussion of this matter

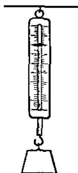


Fig 1 1 The weight of a body can be determined by a spring balance

It is obvious that a body without mass would be weightless (indeed it would not exist), yet mass and weight are different concepts Mass, however, is considered by the physicist to be the more basic concept of the two, and the unit of mass is arbitrarily defined A certain piece of platinum, *having just this characteristic by definition,* is preserved in London along with the English standard yard, and its mass is defined as a pound mass See fig 1 2 The United States pound is legally defined as a certain fraction of the mass of the international kilogram (see below) The standard pound of weight is now defined as the pull of gravity at a specific place (sea level and latitude 45°) on this one-pound mass It is a fact that the pull of gravity on a body (its weight) varies slightly from point to point on the earth's surface, being greater at the poles than at the equator because at the poles it is nearest to the center of the earth But at sea level and in latitude 45° (as London) the standard unit of mass and the standard unit of force are thus simultaneously defined in terms of a specific piece of platinum

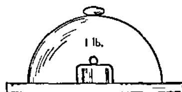


Fig 1 2 The standard pound mass is preserved under a glass cover in London

In a similar manner, another particular piece of platinum pre-

served near Paris is said to have a mass of one *kilogram* One one-thousandth of this mass is called a *gram*, a unit which is generally accepted as the working unit of mass in the metric system, although the kilogram is the fundamental standard

The metric system is a decimal system and has been accepted almost universally in scientific work because of its convenience Engineers, however, both in Great Britain and the United States lean toward the English or the so-called British Engineering system of units, on the ground that it is more familiar to most people This difference might well be used to illustrate an important distinction between science and engineering Whereas science deals for the most part with truths systematically organized into a body of knowledge, with logic carried right down to the matter of units, engineering deals more with the applications of science toward commercially practicable ends Compromises are frequently made with accepted customs and usages by practical people Of course in the last analysis, there is much overlapping, and no one should attempt to distinguish too sharply between science and engineering

Unit of Time The last in this discussion of the fundamental units is the unit of time Whereas time is often defined as a measure of duration, duration can only be defined as a measure of time Thus time is a basic concept, not to be defined but rather to be measured in units It has become almost universal practice to measure time by the use of clocks which have been calibrated to read in terms of the time required for the earth to rotate about its axis in its orbit about the sun The mean solar day is the accepted unit, of which the mean solar second is a 1/86400 part The length of the mean solar day is found by averaging over the whole year This unit is used in both metric and English systems, and thus does not share in the confusion created by the other units See fig 1.3

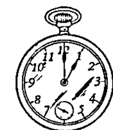


Fig 1.3 Intervals of time are measured by clocks

Systems of Units In brief, then, we have outlined the basic units in two systems The particular metric system in which length is measured in centimeters, mass in grams, and time in seconds is called the C G S (centimeter, gram, second) system

At the present time an attempt is being made to popularize the use of a metric system called the M.K.S. system in which the meter is actually used, not just defined, as the fundamental unit of length, and the kilogram is actually used instead of the gram as the fundamental unit of mass. This system is a compromise between scientists and engineers, and its merits lie chiefly in the electrical units which come later in this study. Of course, the adoption of this system will be a gradual process. In this text all metric measurements will be expressed in C.G.S. units. Where English units are used, lengths will always be expressed in feet, force (not mass) in pounds (see chapter III for further considerations of mass and force), and time in seconds. In terms of such units the physicist records the direct measurements upon which his conclusions are reached and tested.

Measuring Instruments. It is also seen that, in the last analysis, direct measurements boil down to scale readings of

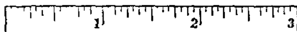


Fig. 1.4. Intervals of length are ordinarily measured by foot rules, yardsticks, meter sticks, etc.

length, clock readings of time, and pointer readings of mass. See figs. 1.4 and 1.5. Such pointer readings of mass are obtained with a balance by the use of which the tendency of a body placed in one pan, to be pulled downward by gravity, is balanced by supplying an equivalent amount of standardized mass in an adjoining pan connected to the former by a bar resting on a knife

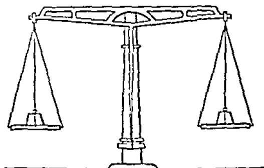


Fig. 1.5. Mass is measured by the beam balance.

edge at its center In the course of his work the physicist has invented ingenious devices to facilitate these measurements, including *the vernier and the micrometer calipers* (see figs 1 6 and

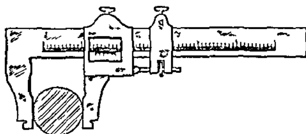


Fig 1 6 The vernier caliper is used to make accurate measurements of relatively short lengths

1 7), the measuring microscope specialized forms of mass balances, and intricate clockwork mechanisms Fundamentally, however, scale readings of length, mass, and time constitute all the direct quantitative observations

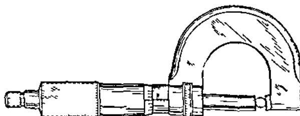


Fig 1 7 The micrometer caliper is used to make accurate measurements of very short lengths

Relative Value of Quantitative Considerations Now, lest the beginning student should get the impression that this discussion of fundamental units appears to emphasize the numerical aspect of the subject in spite of promises that this book would minimize quantitative considerations, he should be reminded that much of the beauty of the science of physics to the physicist lies in its high degree of organization and the discipline which its strict definitions provide In studying such a subject, even if the quantitative or numerical aspects are not pursued to the limit it is well worth noting the importance of getting first things first Only thus does one get the correct orientation prop-

erly to appreciate the more complicated, and perhaps more fascinating aspects of the story which is to be unfolded in the subsequent chapters of this book

Summary In summarizing this chapter we see that physics is to be considered as a logically organized body of concepts to be understood in terms which are uniquely defined By inductive reasoning based upon observation, conclusions are drawn regarding these concepts These conclusions must be subjected to tests of further experimentation and observation Although inductive reasoning is paramount to the research phases of the science—as true today as ever since the earliest times—deductive methods are used to advantage in passing the results on from one generation to another

In this chapter the importance of measurement has also been emphasized but only to serve as material upon which to build The physicist uses measuring instruments as well as instruments of the mind in making his observations, and expresses his results in terms of suitable units, of which there are a few more basic than the rest

Future chapters will deal with some of the results of measurement and although measurement naturally suggests arithmetic, the latter will be minimized so as not to interfere with descriptions of physical concepts Before going on immediately to a detailed discussion of physical concepts, however, attention will be given in the next chapter to the place of physics in our civilization by a brief treatment of the history of the science of physics Such a historical summary will constitute something of an over-all look at the field before a detailed consideration of the various parts is undertaken

QUESTIONS

1 What is meant by the "Scientific Method"?
2 Distinguish between the meter, yard, foot, centimeter, millimeter
3 For what purpose is the vernier caliper used?
4 What is the difference between "inductive" and "deductive" reasoning?

CHAPTER II

HISTORICAL CONSIDERATIONS

ANCIENT AND MEDIEVAL PHYSICS THE NEW AWAKENING IN PHYSICS CLASSICAL PHYSICS MODERN PHYSICS

In a descriptive survey of physics it is appropriate to consider before getting absorbed in the detailed concepts of the subject matters of a broad nature, such as historical developments By such a procedure the student is provided an opportunity not only to appreciate how the science has grown but also to evaluate its importance in and to, modern civilization After all this is a scientific age and it is indeed a matter of some concern to the serious student to find out just what physics has contributed to his world This point becomes all the more significant when it i noted that physics is one of the oldest and one of the most highly organized of all the sciences

Certainly the contribution of physics to the cultural and economic welfare of mankind has been very great indeed in time of both peace and war throughout the ages It is the purpose of the present chapter to outline some of the important developments in the science and to associate them with persons Too often the student of science or technology overlooks the fact that physics is just as much concerned with people as it is with things Discoveries of natural laws are made by persons whose own lives as well as those of others are affected by them It is therefore appropriate that this historical outline be developed around the names and dates of famous physicists The student should try to associate the dates with world events with which he may be familiar outside the realm of science Possibly some connections between events of great social import and discoveries in science will be noted that have not previously attracted his attention

Four Periods of Physics It seems natural to consider this historical survey in four main subdivisions which we shall refer to as periods of physics, as follows *Ancient and Medieval Physics*

(roughly 3000 B C to 1500 A D) *The New Awakening in Physics* (1500 to 1700), *Classical Physics* (1700 to approximately 1890), *Modern Physics* (1890 to the present time) These dates can be considered only as very approximate The first and last of these periods might be subdivided further A distinction could well be made between the ancient and the medieval periods but the contributions made in the latter period, which might be said to extend from 500 A.D to 1500 A D, were so few as to make such a distinction hardly worth while Moreover, the advances made in the so called modern period have been so numerous that a break around 1925 might seem justifiable Perhaps the advent of the atomic bomb in 1945 will make historians of the future consider this year the beginning of a new era However the present is not the time to evaluate the progress of contemporary physics and so it has seemed best in this survey to group all the accomplishments since 1890 into a single so called modern period

First Period Ancient and Medieval Physics (3000 B C–1500 A.D) Records indicate that the ancient Babylonians and Egyptians as early as 3000 B C were familiar with some of the fundamental principles of physics, especially those dealing with the measurement of land There is also evidence that the beginnings of astronomy were somewhat understood by these early people But nothing very definite in a scientific sense, seems to have come from this Of course we recognize the engineering achievement represented by the pyramids of Egypt, but the astronomy was more the sort of thing now known as astrology It also seems certain that the Chinese were familiar with the magnetic compass earlier than 1000 B C, but here again the records are very scanty

THE GREEK PART OF THE FIRST PERIOD From approximately 700 B C to 150 A D very definite advances in physics were made by the Greeks *Thales* (640?–546 B C), a rather shadowy figure, appears to have recognized certain aspects of what today is known as static electricity Historical scientists also credit him and a group associated with him known as the Ionian School with the crystallization of the view that *Fire Water*, and *Earth* were fundamental substances This certainly represented a recognizable beginning of scientific thought

Other early names encountered in the records are *Pythagoras* (580–500 B C) and *Democritus* (460–370 B C) The former is

membered as the founder of the Pythagorean school of philosophers, his most important contribution was probably the Pythagorean theorem of geometry, which states that the hypotenuse of a right triangle equals the square root of the sum of the squares of the sides Democritus is credited with postulating an atomistic view of matter Although an atomistic view is held today, Democritus is not considered its father since there appears to have been little if any scientific basis for his postulate It is more appropriately referred to as idle speculation than as a scientific postulate

Next we come to *Plato* (427?–347 B C) and his pupil *Aristotle* (384–322 B C) Plato was undoubtedly one of the greatest of the Greek philosophers, yet his contributions to physics were relatively meager His famous pupil Aristotle, however, was the great organizer of scientific knowledge of his time He is credited with having written the first textbook in physics He also contributed so much to the science of physics that for many centuries his influence was paramount In spite of his greatness, however, we criticize Aristotle today on the ground that his famous theories were not based primarily upon experimental evidence Although he frequently refers to the value of observed facts in the development of a theory, he seems not to have followed his own advice very conscientiously Much of his work is based upon abstract argument not substantiated by observation It is often stated that Aristotle was more concerned with explaining "why" things were than 'how' nature behaved Modern science, of course, is based on the latter point of view with considerable emphasis upon quantitative measurements made as nearly exact as possible By present-day standards Aristotle was certainly the 'armchair' type of philosopher whose conclusions were more deductive than inductive Although observation was not entirely missing, it was more of the passive curiosity type not accompanied by purposeful experimentation Nevertheless Aristotle's name was unquestionably one of the greatest, if not the greatest, in the Greek period of science

Another Greek of importance was *Euclid* (450?–374 B C) Although he made contributions to geometric optics, his fame is much greater in the field of mathematics than in physics

Finally, in the Greek period, we encounter *Archimedes* (287?–212 B C) of the Alexandrian school On the practical side Archi-

medes is perhaps the best known of all the Greek physicists Today he would be called an engineer or an engineering physicist by virtue of his many applications of physical principles to wartime as well as peacetime pursuits Yet there are also those who would call him the founder of mathematical physics because of his apt and accurate applications of mathematics His work in hydrostatics alone would make him one of the most famous of the ancients, but he made notable contributions to optics, mechanics hydraulics, and other fields of physics as well Unlike Aristotle, however, he interested himself in practical matters, or, as would be pointed out today, he kept his feet on the ground

In summarizing the Greek period as a whole it seems fair to state that the entire period was characterized by deductive rather than inductive reasoning, that observation was for the most part superficial rather than critical, that there was more passive curiosity than active experimentation and more armchair speculation than fact finding Today one cannot help wondering why this was all so Yet it must be remembered that experimentation in physics is a manual procedure and that the social status of the free born Greek citizen above the slave forbade manual labor Whereas the impact of science on society is ordinarily acknowledged, we note here a definite impact of society on science, for it is undoubtedly true that had manual activity not been frowned upon in this period, more advancement would have been made by the Greeks Instead, the science of physics proceeded just so far and no farther in a period of several hundred years compared with the enormous advances made in just a few years in our time

The Latter Part of the First Period Although the first period continued until about 1500 A D, practically no advance in physics was made between 50 B C and 1550 A D This period covers the rise and fall of the Roman Empire, coinciding with the decline of Greek culture generally, and the overrunning of the ancient western world by the barbarians The Romans gradually absorbed Greek culture, but by 600 A D all Europe had been deprived of the opportunity to avail itself of it The Romans were not scientifically inclined Practically all Greek manuscripts [illegible] to Arabia In a way, Greek science was thus preserved fo[illegible] terity by the Arabs who themselves added very little to it [illegible] did, however, introduce to science the so-called Arabic [illegible]

numbers *Alhazen* (965?–?1039) produced a work on optics to be sure, but generally speaking Greek science was not improved upon to any appreciable extent by its translation into Arabic It was still based upon the authority of Aristotle

Between 700 and 1100 A D a beginning was made toward a revival of learning in Europe Large universities developed under the shelter of the church Trade spread, and both Greek and Arabian manuscripts gradually found their way back to Europe The crusades also assisted in this process Since the church had survived the Roman state and become all powerful, it was natural that the revival of learning, and of science in particular, should take place under its influence Many of the scientific manuscripts were translated from the original Greek into Latin by the monks in the monasteries These scholars, like the Greeks, also scorned manual labor and so the science which they passed on to the world was the original Aristotelian version unadulterated by any experimentation of their own Thus the authority of Aristotle was carefully preserved In this period the scholars stuck to the Greek and Roman numbers, leaving the Arabic numbers to trade and so even the Arabian influence was minimized This is another reason why it becomes possible to state that for approximately 1500 years there were practically no advances over Greek science It was certainly a period of scientific stagnation By the year 1500 or so science had just about returned to the status which it had occupied 1500 years earlier Nevertheless the church had re established science in the various large universities, directly under its control It is easy to see, however, that church domination flavored it to suit itself The doctrines of Aristotle came to have the power of law behind them Truth was not discoverable, by that time, it was dictated by the church, and it became a crime of the first order even to question the church sponsored views of Aristotle, to say nothing of suggesting that experimentation might be a better way to establish the truth Naturally science degenerated under this system, in which it became so interwoven with ecclesiastical doctrine that scientific facts could not be separated from religious dictates The time was not quite ripe for the new era which was to dawn about 1550

Second Period The New Awakening in Physics (1500–1700) As time elapsed and trade developed wealth increased This led to the development by wealthy merchants of univer-

sities for study and research outside the church This movement nurtured a growing dissatisfaction with authority in science By 1550 doubters of Aristotle appeared with experimental proof of their views That is to say, doubters began to express themselves openly As a matter of fact there had probably always been doubters but they had been successfully suppressed Two centuries earlier *Roger Bacon* (1214?–1294) had taught that belief should be based on observation and experimentation rather than on authority, but such expressions resulted in his spending practically the last third of his life in prison Truly he was a man who lived at least two centuries ahead of his time

Also, in Italy, there was *Leonardo da Vinci* (1452–1519) But in spite of the great accomplishments of this man in practically every field of the arts and sciences, he was hardly known in his time and his influence was practically nil He left his works in manuscript form and they have come to be appreciated only in recent times Now it is realized that he actually was one of the great scientists of all time

The period of new awakening really commences with *Copernicus* (1473–1543), *Galileo* (1564–1642), *Tycho Brahe* (1546–1601), *Kepler* (1571–1630), and *Gilbert* (1540–1603), who all paved the way for the great *Isaac Newton* (1642–1727) Copernicus developed the heliocentric theory of the universe Galileo, Tycho Brahe, and Kepler established the fundamental ideas of modern celestial mechanics, based upon observation first and theorizing afterward, thus revolutionizing scientific thought Galileo in particular stressed the idea of controlled experimentation to such a degree that today he is recognized as the father of the modern scientific method based upon inductive rather than deductive learning However, he, as well as some of the others, paid the price of propagating revolutionary ideas by spending periods of his life in prison

Galileo carried observation to the quantitative stage by making accurate measurements He truly emphasized the how' (even the 'how much") as contrasted with the why" of Aristotle By his quantitative observations on falling bodies and other mechanical motions, assisted by instruments of his own invention to improve the accuracy of his measurements, he laid the foundation for the discoveries of Newton, who was born the year he died His work was not limited to the field of mechanics, how-

ever His contributions to other fields, including optics, were numerous

Sir Isaac Newton is usually considered the greatest scientific genius the world has produced He crystallized the scientific thought of his time into a few fundamental statements now accepted as laws of nature These include three famous laws of motion and the law of gravitation in the field of mechanics alone In addition, he invented the calculus and contributed greatly to the field of optics His role was primarily that of a co ordinator of information or a systematizer of knowledge He formulated the over-all pattern by which scientific knowledge was to be organized in the great classical period that was to follow his time and which has not yet become outmoded, even today, except perhaps in the restricted field of atomic physics By 1690 much of mechanics was known and fitted into the Newtonian pattern

Newton s contemporaries include *Huygens* (1629–1695), who proposed the wave theory of light in opposition to Newton, and other famous physicists including *Boyle* (1627–1691), well known in connection with gas laws and *Hooke* (1635–1703), whose work in elasticity is famous *Pascal* (1623–1662) is remembered for his law of fluid pressure

Thus the second great period in physics ends around 1700 or so, when the ideas of Galileo, Bacon, and others, who were irked by the doctrines of Aristotle forced upon them by the church, finally took hold and opened up a vast new era It was certainly a period of New Awakening and it paved the way for the physics of the eighteenth and nineteenth centuries, during which time new discoveries, although made in rapid succession, seemed to do hardly more than confirm the broad structure of the science laid down by Newton

Third Period Eighteenth and Nineteenth Century Classical or Newtonian Period (1700–1890) It will not be feasible in this historical survey to enumerate all the achievements of the eighteenth and nineteenth centuries The science of physics was really gathering momentum by this time and becoming very complicated The science was getting large enough for the various subdivisions to be significant Advances were made in the fields of mechanics, heat, light, and electricity, as if each branch were more or less independent, but the work of Newton provided the

means of integrating all this knowledge In a way the period can well be described as one in which the fundamental views of Newton gradually came to be appreciated and established A wealth of quantitative material was gathered, but it all seemed to fit together in a most remarkable way into the Newtonian pattern Indeed, the success of Newtonian physics was so great that by the end of this period it almost seemed that the end of physics was in sight Almost everything seemed settled, hence the designation classical period'

Rather than attempting to develop this period in a chronological order as in the case of the two preceding periods, we shall consider the various branches of the science separately and do hardly more than list the outstanding names, dates, and events in this period Commencing with mechanics, we note the work of *Bernoulli* (1700–1782) in hydrodynamics and gas theory, *D Alembert* (1717?–1783), *Euler* (1707–1783), *Lagrange* (1736–1813), and *Laplace* (1749–1827) in theoretical mechanics

In the field of heat, the period 1600 to 1800 saw the development of thermometers and temperature scales by Galileo, *Fahrenheit* (1686–1736), and others It also saw the introduction of the concepts of latent and specific heats by *Black* (1728–1799) and the development of the steam engine by *Watt* (1736–1819) The nineteenth century saw the concepts of heat fitted into the Newtonian picture by the work of *Rumford* (1753–1814) *Joule* (1818–1889), and *Rowland* (1848–1901) These men established the view that heat was merely a form of energy *Carnot* (1796–1832), *Mayer* (1814–1878), *Helmholtz* (1821–1894) *Kelvin* (1824–1907), *Clausius* (1822–1888), and others established the fundamental laws of thermodynamics, in which the basic concept of energy served to unify the concepts of heat with those of mechanics Finally we note the work of *Gibbs* (1839–1903) in chemical thermodynamics and later in statistical mechanics closely related to the subject of heat

Also in the field of light, many advances were made in these two centuries, and again the unifying influence of the Newtonian methods was very apparent in the latter one Galileo had attempted to measure the velocity of light but had found it too great for accurate determination *Roemer* (1644–1710) and *Bradley* (1693–1762) made more successful determinations, arriving

at values not too far different from that accepted today—around 186 000 miles per second *Foucault* (1819–1868) and *Fitzeau* (1819–1896) refined the measurements around 1850, but the final result waited for *Michelson* (1852–1931)

Huygens wave postulates were revived by the work of *Young* (1773–1829) and *Fresnel* (1788–1827) *Malus* (1775–1812) discovered the phenomenon of polarization of light by reflection This work was extended by *Brewster* (1781–1868) *Fraunhofer* (1787–1826), *Kirchhoff* (1824–1887), and *Bunsen* (1811–1899) laid the foundation for modern spectroscopy

The crowning climax of this period in the field of light was the stroke of finality given to the age-old question of the nature of light, whether corpuscular or wavelike, by the great *Maxwell* (1831–1879), whose electromagnetic wave theory of light satisfied all parties to the controversy As a matter of fact, Maxwell is considered by many to be the greatest theoretical physicist of the nineteenth century as a result of his extraordinary accomplishments in the fields of light and electricity

The last field to be considered in this third period of physics is that of electricity, or electricity and magnetism, for it was found in this period that these two fields were really one Probably more attention was given to electricity than to any other branch of physics during the eighteenth century *Gray* (1670–1736), *Du Fay* (1698–1739), *Franklin* (1706–1790), *Cavendish* (1731–1810), and *Coulomb* (1736–1806) did significant work in electrostatics *Galvani* (1737–1798) and *Volta* (1745–1827) were pioneers in current electricity In the latter part of the period the outstanding contributors were *Faraday* (1791–1867), *Henry* (1797–1878), and *Maxwell* (1831–1879), although they had many contemporaries, including *Ampere* (1775–1836), *Wheatstone* (1802–1875), *Lenz* (1804–1865), *Kelvin* (1824–1907), *Kirchhoff* (1824–1887), and *Hertz* (1857–1894) Faraday was the outstanding experimentalist of his time, and Maxwell, as stated earlier, was probably the most outstanding theoretical physicist of the period In this field, as in all the others, the period ended with a great feeling of satisfaction by physicists that the science of physics was finally organized and very well integrated Remarkable generalization had been accomplished by the theoretical physicists especially Maxwell, utilizing the general methods of Newton and the highly successful concept of energy It was in

deed the classical period in physics So complete was the picture and so satisfied were the physicists in their accomplishments that by 1890 a general feeling became widespread, although it is diffi cult to determine its precise origin that physics was about done, that probably no startling new discoveries would ever be made, and that probably future generations of physicists would have to content themselves with merely extending the accuracy of known information, perhaps to the next decimal place That this was not the case is the story of modern physics which period started just about 1890 when physicists were jolted rather abruptly out of their lethargy by several noteworthy discoveries including the electron, the X ray, and radioactivity

The Fourth Period Modern Physics (1890 to the Present) The great generalizations and correlations in theoretical physics and the refinements of measurement in experimental physics during the nineteenth century, especially the latter part certainly placed the science in a strategic position with respect to the tech nological and industrial activity just commencing The economic world was surely destined to feel the impact of it Indeed not even today has industry come anywhere near to exhausting the applications of classical physics to its needs, even though the fruits of a still more recent period the modern period have come to occupy front place on the technological scene Of course we refer to electronics television atomic energy, etc, all of which were unheard of much before 1890 But it is still classical or Newtonian physics which properly constitutes the major part of a college program in physics today, especially for those students anticipating a career in engineering In fact this text also will be largely classical in its scope The so called newer physics which is the material covered in the fourth period cannot prop erly be understood and evaluated without a substantial back ground in classical physics

Although the achievements of the nineteenth century were out standing the impression must not be given that perfection has been attained There were gaps here and there, and there were certain inconsistencies For example the electromagnetic wave theory of light was wonderful but it required the postulate [illegible] a medium the luminiferous ether, for the waves to wave [illegible] one could find any tangible evidence for the existence of [illegible] medium Also the study of heat radiation was not qu[illegible]

Furthermore, recent discoveries in electricity, such as the photoelectric effect by which the action of light produces an electric current, were inconsistent with Maxwell's theory of light Yet all such difficulties were considered to be of very minor importance compared with the over-all success of the general Newtonian pattern It was felt that sooner or later they would all be straightened out, like a jigsaw puzzle complete except for the last few pieces The fact is, however, that instead of this happening the difficulties became enormously magnified as physicists concentrated their attention on them It finally took a whole new point of view, such as is utilized in the quantum theory and in relativity, to straighten things out But this did not happen until a series of brand-new discoveries were made, including the isolation of the electron, radioactivity, X rays, and the concept of the electrical structure of matter, all of which were likewise explained by the new viewpoint

Crookes (1832–1919) had discovered cathode rays in 1878, but *J J Thomson* (1856–1940) explained their nature as negatively charged electrical particles, called electrons This was between 1890 and 1897 and is usually referred to as the beginning of the electronic era, although *Stoney* (1826–1911) had suggested the name "electron" as early as 1874 *Lorentz* (1853–1928) formulated an electron theory of matter in 1895 in which vibrating electrons accounted for the electromagnetic radiations predicted earlier by Maxwell and discovered in 1888 by *Hertz* (1857–1894)

Also in 1895 *Roentgen* (1845–1923) discovered X rays, and in 1896 *Becquerel* (1852–1908) discovered radioactivity These were followed in close succession about 1898 by the isolation of polonium and radium by the Curies, *P Curie* (1859–1906) and *M. Curie* (1867–1934)

The year 1900 is marked by the introduction of the quantum theory by *Planck* (1858–1947) This, followed by the theory of relativity in 1905 by *Einstein* (1879–   ), set the stage for many advances because of the new way these two theories provided for viewing natural phenomena These theories struck at the fundamental philosophy of physics and provided the key to the solution of several problems left over from the preceding period The quantum theory explained heat radiation and the photoelectric effect almost immediately The theory of relativity went farther

than Newtonian mechanics to explain certain phenomena associated with matter moving with extraordinarily large velocity, such as electrons, atoms, and molecules It also provided an explanation for the failure of the Michelson Morely experiment (1887) to determine the drift speed of the earth through the luminiferous ether Although these theories were very reluctantly received, they have nevertheless gradually become established in physics, in spite of the fact that they have so altered scientific thinking that many of the older physicists of today have confessed their inability to reconcile some of the postulates with classical physics or even with common sense Indeed, much of the newer theoretical physics is abstract mathematics, but most of the younger physicists have come to accept the results of these two theories as reasonable

From about 1911 much interest has been focused upon the general field of physics known as atomic physics *Rutherford* (1871–1937), with the help of many assistants over a period of years, finally established the concept of the nuclear atom *Bohr* (1885–) devised a model of the atom in 1913 which was patterned after the solar system and its planets This so called planetary atom, consisting of a positively charged nucleus encircled by negatively charged electrons, has been very widely publicized Although today this picture has been more or less replaced by abstract mathematical representation in the mind of the theoretical physicist, many of the Bohr features are still useful, especially in elementary explanations of atomic phenomena

To the uninitiated this last statement may seem strange, raising as it probably does the question of how a picture can be accepted if it is not correct. This is an example, however, of the modern point of view in physics, and its relation to common sense Quantum and relativistic physics have prepared the scientific mind to appreciate how complex nature really is, and how far the world of atoms and electrons is removed from that of common sense anyway It reminds us that explanations are only relative to the student's background To an elementary student something can be a perfectly satisfactory explanation which would not be appropriate for the advanced student. In other words, there can be any number of ways of explaining anything It is not a question of which is the correct one, it is rather a

question of which is the better one for the purpose Thus perhaps it is clear how the newer physics has seemed so confusing to the older generation

Many names might be mentioned in connection with atomic physics, but in this brief summary only a few seem appropriate *W H Bragg* (1862–1942), *Aston* (1877–), *C T R Wilson* (1869–), and *Millikan* (1868–) are all names which attained prominence before *1920 Of course no distinction can be* made here between atomic and electronic physics, and furthermore these lists are very far from complete

During the 1920 s further advances were made in electronics, spectroscopy, and nuclear physics, although research in all fields increased greatly after the First World War *A H Compton* (1892–) practically removed the last traces of doubt of the quantum theory in 1923 by his experiments with X rays *De Broglie* (1892–) introduced the concepts of wave mechanics in 1924 *Heisenberg* (1901–), *Dirac* (1902–), and *Schrödinger* (1887–) did much to develop this field between 1921 and 1926 *Davisson* (1881–) in this country and *G P Thomson* (1892–) in England produced experimental evidence for the wave nature of the electron in 1927 and 1928

In 1932, *Chadwick* (1891–) discovered the neutron, a fundamental particle which carries no electrical charge, and *Anderson* (1905–) discovered the positive electron sometimes called the positron *Lawrence* (1901–) invented the cyclotron in this same year *Joliot* (1900–) and his wife *Irene Curie-Joliot* (1897–) discovered artificial radioactivity in 1934 *Fermi* (1901–) and others produced artificial radioactivity by neutron capture *Hahn* (1879–) in 1938 discovered uranium fission, which is the basis of the atom bomb of 1945

Thus we have touched upon some of the high points of physics right up to the present time As stated before, the list of names and dates is far from complete, nor is it intended that the elementary student should understand all of the above, but enough has been included to maintain the continuity Research today, however, is not a matter for individual physicists This is the *age of group research, and in many of the projects noted above* only the leader or leaders have been mentioned Hundreds of

others have contributed who may never receive full recognition for their work

It has been the aim of this chapter to outline the advances in physics from almost prehistoric times up to the present It should be obvious that these advances have been made at an accelerated rate except for the dark period between 50 B C and 1500 A D Today, physics is progressing at such a rapid rate that we can only guess what will be discovered and what the consequences will be in the future Certainly the atomic bomb has indicated how closely the affairs of this world are related to the developments in the physics laboratory, and it can only be hoped that man can learn to get along with his kind as fast as he can discover the secrets of nature, lest things get out of control and he annihilate himself

In a way this chapter has been something of a summary of the whole field of physics but one developed chronologically rather than logically Following chapters will deal with much of this material in amplified form

QUESTIONS

1 How can the Greek period in physics be briefly characterized?
2 Why were Aristotle's views so widely accepted as late as the fifteenth century?
3 What is meant by the statement that the Arabians left Greek science in cold storage' ?
4 Why is Galileo considered the father of modern science?
5 Why is the classical period often referred to as the Newtonian period in physics?
6 What broad fields characterize modern physics?

question of which is the better one for the purpose Thus perhaps it is clear how the newer physics has seemed so confusing to the older generation

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tant point that when two forces of equal magnitude are added together, i e, act upon the same body, the result is not necessarily a force with twice the magnitude of one, but one which

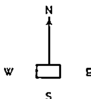


Fig 3 1 No effect in easterly direction



Fig 3 2 No net effect

may even be zero, depending upon the directions involved The result is a doubled force only when the two forces point in the same direction See fig 3 3 When the directions of two forces of *equal magnitude* happen to make an angle of 120° (an angle of 120° is one third of a whole circle) it can be shown, both by calculation and by experiment, that the resultant force—that is the force which by itself would produce the same effect as the other two combined—has exactly the same magnitude as each of

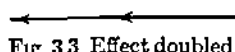


Fig 3.3 Effect doubled

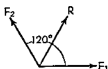


Fig 3 4 R has same magnitude as F_1 and F_2

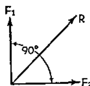


Fig 3.5 Magnitude of R is approximately 1 4 that of F_1 or F_2

them (no more, nor less) although of course the resultant direction is quite different from either See fig 3 4 Another special case is the one in which two such forces make an angle of 90°—i e a right angle—with each other Here is a force of about 50% greater magnitude than each, which points in a direction lying halfway between the two See fig 3 5

Composition and Resolution of Forces The student sh[illegible]
be interested in knowing how these results are determined [illegible]

a matter of experience, of course, that they are true, but the fact that they can be determined without resort to experiment, except to check the answer, is very important The simplest way to determine a resultant force is to represent each force graphically by an arrow drawn to scale, so that its length indicates in a relative way the magnitude of the force, and so that it points in the prescribed direction If, now a drawing is made with the tail end of one arrow joined to the head end of the other, each pointing in its proper direction, the straight line drawn from the tail end of the latter to the head of the former will indicate by its length and direction (using the same scale) the magnitude and direction of the resultant See fig 3 6 This is obviously the diagonal of a parallelogram made by the pairs of the two arrows as sides Such arrows are called *vectors* and force is a vector quantity That is to say it is a quantity which requires the specification of direction as well as of magnitude for its complete determination Vector quantities of which there are many in physics, can be added (compounded) by such a graphical method as just described and of course, the procedure is not limited to just two vectors There are also rules of mathematical physics by which vectors may be subtracted multiplied divided, etc, but it is not necessary for us to consider these here

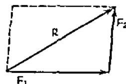


Fig 3 6 Vector addition

Thus we see that forces may be compounded to produce resultant forces A question then naturally arises May not any force be considered to be such a resultant of perhaps several subsidiary forces —i e may not a force have certain components into which it may be broken down for convenience The answer is obvious, and for practical considerations, very important A certain force pointing in a northeasterly direction for example may be considered to be the resultant of a force in a northerly direction combined with a force of the proper magnitude, according to the graphical procedure just outlined pointing in an easterly direction, even though these two forces may not be apparent See fig 3 7 The latter two

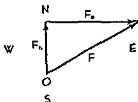
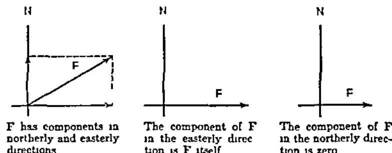


Fig 3 7 F may be thought of as the resultant of F_n and F_e

forces are said to be components of the original one A force may thus be broken down into any number of components The projected component of a force in the same direction as the force is the entire force itself, while the projected component of a force at a right angle to itself is zero See fig 3.8



F has components in northerly and easterly directions

The component of F in the easterly direction is F itself

The component of F in the northerly direction is zero

Fig 3.8

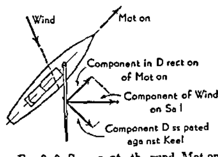
It should be clearly borne in mind that it is frequently inconvenient to exert a force in the right direction to get its full benefit For example, it is probably more convenient to tow a barge through a canal by pulling a rope obliquely from the shore than to tow it directly behind another boat See fig 3 9 Again, it is probably much more convenient for a tall person to pull a sled by a rope which makes an appreciable angle with the ground, although the full benefit of the pull would be realized only if the pull were made horizontally In these cases one is satisfied with



Fig 3.9 Towing a boat by pulling at an angle to the direction of motion of the boat

only one component of the force exerted On the other hand, in the case of a sailboat, it becomes possible to sail almost directly into the wind only because the sail can be set at such an angle that the force of the wind perpendicular to it has a component in the direction of the desired motion of the boat The remainder of the wind s force is dissipated indirectly by means of the keel of the boat See fig 3 10

In these simple cases we have developed the view that not all of a force need be utilized. Lest this create the false impression that the components of a force are always small as compared with the resultant, other cases should be considered. When the angle between two forces of equal magnitude, acting at a point, exceeds 120° the magnitude of the resultant force is less than that of either force alone. See fig. 3.11. As greater and greater angles are considered the corresponding resultants decrease more and more in magnitude. In the limit, when two such forces act in opposite directions (180° apart), as in the example considered early in the chapter, the resultant is zero. Also, when the angle between two forces is almost 180°, a small force acting as the resultant has components along the prescribed directions of much greater magnitude than the force itself.



the wind blows obliquely upon a sail the sail appreciates only the component perpendicular to itself, i.e. the wind can push on a sail only perpendicularly

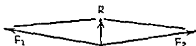
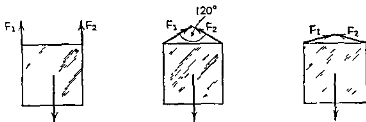


Fig. 3.11. Case of R whose magnitude is much smaller than that of components F_1 or F_2

This is easily tested by experiment. If a heavy package in the shape of a cube is lifted by a cord wrapped about the package,



F_1 and F_2 each equal to half the weight of the box.

F_1 and F_2 each equal to the whole weight of the box

F_1 and F_2 each greater than the weight of the box

Fig. 3.12

the cord is quite likely to break when the cord is wrapped quite tightly On the other hand, if the cord is so loose as to make only a small angle at the point where the cord is lifted, it is not broken so easily When the cord makes an angle of nearly 180° at the point where it is lifted, as in the case of the tightly wrapped cord,

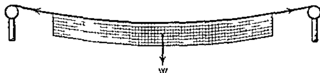


Fig 3 13 Tension in tennis net approaches infinity as the slack is almost taken up

the force developed in the direction of the cord becomes infinitely great See fig 3 12 This is also why no force whatever is sufficiently great to take absolutely all the slack out of a tennis net if it is applied along the direction of the net See fig 3 13

Equilibrium of Forces First Condition of Equilibrium A consideration of the case where the resultant force is zero when a northward component is compounded with a southward component of equal magnitude also clears up another difficulty commonly encountered by the beginning student It is sometimes hard to understand, if we accept the definition of a force as a push or pull tending to change the motion of a body, how a body can be at rest on a table, i e , be under the influence of no force, when we know that the force of gravity is always acting The answer is, of course, that the table also acts on the body, and that the resultant of this force acting upward, compounded with the weight of the body acting downward, is zero, so that the *net* tendency to move is zero See fig 3 14 If the table were not there to support it the body would move downward Thus a body at rest on a table represents a condition called *equilibrium* It is characterized in part by the fact that the vector sum of all the component forces is zero If, for practical purposes, we should restrict our consideration of components to components pointing upward, downward, toward the right, and toward the left, we may say

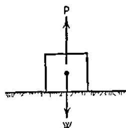


Fig 3 14 Push of table on body balances pull of gravity on body for equilibrium

that for equilibrium to exist all components upward must be balanced by all components downward, and all components toward the right must be balanced by all components toward the left See fig 3 15 This is what is meant by the statement that the vector sum must be zero The realization of this makes it possible for the engineer to calculate in advance the forces which will act upon the various members of bridges and other structures The basic physical principle behind such *calculations* is simply this principle of equilibrium

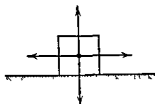


Fig 3 15 First condition of equilibrium requires that forces up balance forces down and that forces to right balance forces to left

This principle is also utilized in the determination of mass by the beam balance as previously indicated, but here a second condition of equilibrium is also involved See fig 3 16

A little reflection shows that there are two general types of motion into which a body may be set by the action of a force These are *translatory motion,* defined as motion in which every straight line in a body remains unchanged in direction through-

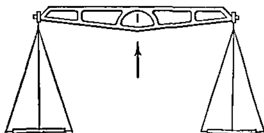


Fig 3 16 Beam balance

out the motion, and *rotary motion,* defined as a motion of a body such that every point of the body rotates in a circle about some axis In the case of the latter, the effectiveness of the force is found to be directly proportional to the distance between the axis and the line of action of the force—i e, it is doubled, tripled or halved, etc as this distance is doubled, tripled, or halved, respectively This distance is known technically as the *lever arm* of the force See fig 3 17 If the line of action passes directly through the axis, no rotating tendency is produced because the

resulting lever arm is zero Thus the tendency to rotate depends upon the two quantities, force and lever arm, which give rise to a concept called *torque* It is defined as the product of a force and its lever arm, with respect to a given axis Torque is some

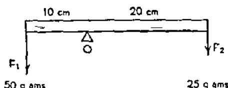


Fig 3 17 50 grams at 10 cm lever arm balances 25 grams at 20 cm lever arm F_1 tends to produce counterclockwise motion about the fulcrum O F_2 tends to produce clockwise motion about the fulcrum O

times called *moment of force Clockwise* and *counterclockwise* rotations are thus capable of being produced by the action of *clockwise and counterclockwise torques*

Second Condition of Equilibrium. The formal statement of the second condition of equilibrium is that the sum of all torques about any axis must be zero, i e, all clockwise torques must be balanced by counterclockwise torques In the use of the beam balance the pull of gravity on a body placed in one pan acting with a certain lever arm with respect to the fulcrum is balanced by the pull of gravity (weight) on standard masses placed on the other pan acting with its lever arm Note[1] if the lever arm of one pan is doubled, only half the force is necessary to maintain the constancy of the torque, i e, to produce a certain tendency toward rotation This is what is meant by the statement that a force is made more effective as regards rotational motion by increasing its lever arm with respect to some axis which serves as a fulcrum Thus machines such as levers and other mechanical contrivances can be devised to facilitate certain tasks, but a more complete discussion of these matters will be reserved until such concepts as work and energy have been developed

Need for Study of Motion In the discussion of forces up to the present point the vector aspect, in particular, has been considered It is obvious, however, that a complete appreciation of the force concept cannot be had until the vocabulary of motion is developed, for the tendency to change motion is an inher

part of its definition Motion, on the other hand, is a meaningless concept until the concept of position is established

Position and Displacement. Position is a relative matter In the three-dimensional world in which we live, bodies are best located with respect to certain landmarks by laying off specified distances in three mutually perpendicular directions from the landmark taken as an origin See fig 3 18 Thus so many paces to the north (or south), then so many to the east (or west), and so many feet up (or down) from a given point will suffice to locate any other point in space with respect to this point A change in position involves a displacement from the first to the second position This is obviously a directional matter See fig 3 19 The concept of change of position in a certain direction is called *displacement*, and is a vector quantity like force This means that in technical considerations a distinction must be made between distance and displacement For example,

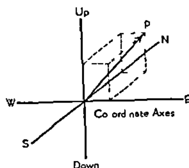


Fig 3 18 Three-dimensional location of point P (north-south east-west up-down)



Fig 3 19 Displacement from A to B with respect to the origin O on a straight line

a car left in a parking lot may later be found ten feet to the right of its original location It is therefore correct to say that the car has undergone a displacement of ten feet to the right, although in so doing it may have been driven a distance of several miles, out of the parking grounds and all over the city, later being returned to the lot and parked ten feet to the right of the original location Displacement, then, is a technical concept and one which is fundamental in the study of motion

Velocity. The next concept to be considered is that of *velocity*, the time-rate of displacement, and again the fundamental natures of length and time are brought out When a displacement takes place in a certain length of time, the ratio of the

displacement divided by the time is called the *average velocity* of the body undergoing the displacement Thus a car traveling twenty miles northerly in one hour is said to have an average velocity of twenty miles per hour northerly Velocity is therefore also a vector quantity and is subject to the laws of vector combination That the direction of a velocity is important is brought out by the example of the rowboat crossing a flowing stream in which the current is appreciable It is obvious that, to reach a specified point on the opposite shore in a given length of time the direction in which the rower points his boat is fully as important as the speed with which he rows *Speed* is defined as the magnitude of velocity, i e, just the amount of it, not considering direction

In this consideration the matter of constancy of velocity has not yet entered Although a car may make a displacement of twenty miles in a given direction in one hour and thus maintain an average velocity of twenty miles per hour, it is common knowledge that the actual rate may be a variable quantity Thus a distinction must be made between average velocity and *instantaneous velocity* The latter quantity implies a measurement made over an infinitesimally small interval of time In a millionth of a second for example it is inconceivable that the velocity of a body can change very much Therefore the average velocity over such a small time interval is accepted as approximately the actual instantaneous velocity If this interval is not sufficiently short for a given purpose then it is agreed that an interval of a billionth of a second should be considered and so on It is thus seen that instantaneous velocity is really an abstract concept in spite of the fact that it has become a common everyday term in this automobile age Strictly speaking the speedometer of an automobile does not measure velocity but only the magnitude of it or speed and the device is therefore correctly named since it does not indicate direction

Acceleration A name is also given to the time rate of change of velocity It is *acceleration* This is a vector concept too because a change in one direction is not the same as a change in any other direction Of course there are various ways in which a velocity may change Either the magnitude or the direction may change or they may both undergo a change simultaneously Although the magnitude change—correctly speaking this is

change of speed—is a common experience, we must not overlook the fact that a change in direction, even with a constant speed, constitutes a perfectly good acceleration Thus a car traveling in a circular path experiences an acceleration although the speed may not change The direction of this acceleration is toward the center of the circle

With this very brief introduction to kinematics the student, if he is disposed toward arithmetic, can already appreciate certain numerical relationships, although as has been stated the e are of secondary importance in this study Thus the product of a constant velocity and the time during which it continues represents the total displacement, a quantity which might not otherwise have been specified in some problem Similarly if a velocity changes uniformly, i e if motion is uniformly accelerated motion, the foregoing relationship between velocity, time and displacement holds, providing average velocity is used In terms of initial and final values the average of any two quantities is one half their sum Thus a car starting from rest (initial velocity zero) and acquiring a final velocity of 60 miles per hour (88 ft per second) has an average velocity of 30 miles per hour (44 ft per second) In ten seconds it will have been displaced 440 ft if the acceleration is uniform

Falling Bodies We now come to our first consideration of a physical phenomenon It is a matter of physical observation that every unsupported body falls in a straight line with constant acceleration, except for the fact that air resistance alters very high speeds See fig 3 20 This means that in a vacuum all unsupported bodies have a constant downward acceleration which has been measured as approximately 32 ft per second per second (i e, a gain in velocity of 32 ft per second each second) In metric units this amounts to 980 cm per second each second Thus the pull of gravity (weight) alone changes the motion of a body by a constant amount each second, i e, at a constant rate This fact has not always been known, and its discovery was a remarkable scientific achievement The acceleration is not readily measured by direct experiment because a body falls 16 ft in the first second from rest and 48 ft in the succeeding second, and a second is a rather short interval of time for precise direct measurements As has been said before, however, physicists starting with Galileo

have devised indirect means of measuring very large and very small quantities, so that today the acceleration of gravity is known with a high degree of accuracy As we have seen (p 7), it varies slightly from place to place on the earth's surface This means also that the weight of a body is not constant but varies as the acceleration of gravity varies See also p 38



Fig 3 20 In an exhausted tube a metallic coin and bits of confetti fall at the same rate showing that air resistance is what ordinarily makes these objects fall at different rates The acceleration of *gravity is the same in a vacuum* for all objects at a given place on the earth s surface

The fact that the pull of the earth gives all unsupported bodies the same acceleration was not recognized prior to the time of Galileo Aristotle had taught that heavy bodies necessarily fall faster than light ones, and even when Galileo demonstrated the fallacy in Aristotle s conclusion by dropping bodies from the top of the leaning *tower of Pisa, all were not convinced* Even in Galileo s time it was not altogether clear that the motion which a body acquired was the result of the force acting upon it

Newton s Laws of Motion The whole matter of force and motion was finally summarized by Sir Isaac Newton (1642–1727) in the form of three generalizations now known as laws of motion In the scientific sense they represent a discovery which has stood the test of experiment ever since Newton's time In simple language they may be expressed as follows

1) Every body continues at rest or in a state of uniform motion unless a force acts upon it

2) If a force acts upon a body, the body experiences an acceleration in the direction of the force and proportional in amount to *it as well as inversely proportional to the mass of the body*

3) Associated with every force there is an equal and oppositely directed reaction force

Significance of the First Law. Let us consider now the significance of these brief but comprehensive statements which have come to be accepted as natural laws The first one makes it clear that no force whatever is required to keep a body moving at a constant speed in a straight line, but rather that a force is necessary to stop such a motion, or indeed to alter it in any way In other words it implies that all bodies exhibit a property known as *inertia* Moreover, a condition of rest is to be thought of as merely a special case of uniform motion Thus we see that except for the necessity of overcoming friction and air resistance no force at all is required to keep an automobile going at 50 miles per hour over a level, straight road Perhaps the drivers of 'free-wheeling' cars have come to appreciate this point, if only to a limited extent

Momentum The common expression that a car is sometimes carried along by its momentum is a popular version of this important law The expression is technically *correct if the correct definition of momentum* is understood, as the product of the mass and the velocity of the body concerned Momentum is another vector quantity and is expressible in terms of arrows Newton often referred to momentum as quantity of motion, thus emphasizing the view that matter in motion is more meaningful than motion in the abstract The first law also provides the theoretical basis for the conditions of equilibrium already discussed

Significance of the Second Law The second law explains how motion is changed by the application of a force In other words it indicates that force is necessary to overcome inertia A mathematical statement would be that force equals mass multiplied by acceleration This is why on p 7 the statement was made that the weight of a body varies slightly from place to place on the earth s surface with the acceleration of gravity Thus we see that mass is not the same as weight, and that the unit of force (dyne) is equal to the unit of mass (gram) multiplied by the unit of acceleration (cm per sec per sec) This is also why the unit pound should not be used for weight and mass (see p 7)

The second law also brings out very clearly that the amount of effort required to change a motion depends proportionally upon the acceleration involved The reason for powerful motors in automobiles is to provide acceleration ability rather than to enable them to travel fast What is popularly called "pickup"

requires the application of force This means that if two bodies of the same mass were to be acted upon by different forces, the one acted upon by the larger force would experience the greater acceleration Furthermore, the same force acting upon different masses would produce a greater acceleration of the less massive of the two bodies Thus the new fast trains are made less massive than the older ones and require much less time to stop and to come up to speed again at stations by the application of forces presumedly equivalent to those utilized in the more massive trains

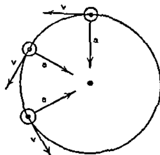


Fig 3 21 A body traveling in a circular path with constant speed has an acceleration directed toward the center due to a continuous change in the direction of the velocity

The second law also explains *centripetal force*, the force necessary to keep a body traveling at constant speed in a circular path, and its reaction (see third law below), *centrifugal force*, both of which are involved when cars skid around curves at excessive speeds See fig 3 21 In this case the acceleration produced by a force is usually the result of change of direction only The centripetal force acts *on* the revolving body whereas the centrifugal force is exerted *by* the revolving body on something else

Significance of the Third Law The third law expresses the observable fact that a force never exists alone It is impossible to exert a force without a reaction force A little reflection con-

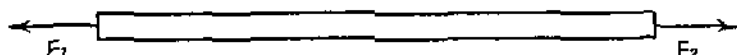


Fig 3 22 A tug of war is not possible unless F_1 opposes F_2 and vice versa

vinces one that a one-man tug of war is an impossibility One cannot exert a force without opposition See fig 3 22 The most powerful automobile in the world is helpless in a snow bank where no traction is provided for the wheels i e, when the snow is too slippery to develop enough frictional force to push the car out Actually it is the push of the ground that makes the car start

Nature of a Scientific Law It must be remembered that these three laws are accepted today as scientific truths The

represent discoveries in the scientific sense, i e, according to the scientific method already described Accepting them as fundamental truths, it is possible to explain all the known phenomena in mechanics Of course it is possible to set up a logical framework of explanations of these phenomena in terms of other assumed truths, but experience has shown that these assumptions are not only most reasonable and natural—based upon experience —but that they are relatively simple Thus the physicist today does not attempt to explain Newton's laws of motion It is sufficient to explain all else in terms of them, and the fact that classical physics can be so explained is one of the marvels of science itself To be sure, not all of the modern atomic physics has fitted so well into this beautiful pattern, but at least in an approximate way we can say that these laws of Newton's constitute one of the most important landmarks in the science of physics Today more inclusive theories must be considered but not to the exclusion of Newton's laws

Newton's Law of Gravitation At this point we mention another all-important contribution by Newton, the law of gravitational attraction In connection with his laws of motion just discussed, it becomes necessary to associate the acceleration of gravity with the force called weight That is to say, some force of attraction between the earth and an unsupported body is necessary to account for the acceleration which the body has toward the earth Newton discovered that by postulating universal gravitational attraction between all bodies in the universe he could, with the aid of his laws of motion, explain the motions of the heavenly bodies and so concluded that such a postulate was justifiable This is now an accepted law It states that every body in the universe attracts every other body with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between them It is referred to as the inverse square law of gravitational attraction The proportionality factor, now known as the gravitational constant, was evaluated quite accurately by Lord Cavendish in the latter part of the eighteenth century in England and more recently by P R Heyl of the National Bureau of Standards in Washington, using large, heavy balls and very delicate methods of measuring slight attractive forces

By this time, the point must be clear that one of the goals of

physics is ultimately to be able to explain everything in terms of the simplest assumptions, and express these explanations in the most comprehensive fashion Thus Newton's laws—three brief statements—and the law of universal gravitation express a wealth of information to those who understand them Of course it must always be remembered that physics, like all science, never attempts to explain the ultimate 'why' of anything but rather the 'how" of it Another such comprehensive and all inclusive statement, or law, is the law of the conservation of energy, which we shall consider presently, but first the concepts of work and energy must be developed The next chapter will deal with these concepts

QUESTIONS

1 What is meant by a vector quantity?
2 How would the arrow used to represent a south wind differ from one representing a north wind? A west wind?
3 How would an arrow representing an upward pull of 30 lbs differ from one representing an upward pull of 50 lbs?
4 If three forces act on an object how would you proceed to find the resultant force?
5 A wire supporting a picture is attached to two points rather close together How does it happen that if the points to which the wire is attached are rather far apart, the wire might break?
6 If a heavy box is dragged at a uniform rate along a horizontal walk and then up an inclined walk, in which case is the greater force probably required? How is this explained?
7 Does the speedometer on a car register speed or velocity?
8 Can a car traveling at a constant speed have an acceleration?
9 If a spring balance reads 15 lbs when a given object is placed on it will it read more or less as it is carried to higher altitudes? Will it read more or less at the north pole? at the equator?
10 Will an equal arm balance which is balanced at the top of a mountain be balanced or unbalanced at sea level?
11 State Newton's three laws of motion
12 Why does the physicist not attempt to prove Newton's laws of motion?
13 What is the difference between centripetal force and centrifugal force?
14 Distinguish between kinematics and dynamics
15 What is momentum?

CHAPTER IV

MECHANICAL CONSIDERATIONS (*Continued*)

WORK, ENERGY, AND FRICTION

The Concept of Work. *Work is a concept which, in physics*, does not have quite the same meaning as in popular usage, where it seems to imply physical exertion In fact, it is difficult to tell just what is meant by the term "work" in a popular sense, in view of the many arguments over what constitutes and what does not constitute work It is a technical term here, and as such has to be used in a very exacting manner When a body is displaced, a force may or may not be acting upon it depending on whether or not the body is accelerated If a force is acting on a body when the latter is displaced and if the direction of the displacement is the same as the direction of the force, then *work* is said to be done on the body If the direction of the force should be perpendicular to the direction of the displacement or if there is no displacement, then, technically speaking, there is no work involved Thus *work* is an abstract concept defined as the product of force multiplied by the displacement of the point of application of the force in the direction of the force See fig 4 1 This is the same as the product of the displacement multiplied by the component of the force in the direction of the displacement In either event, the two quantities which are multiplied to yield work must point in the same direction, and furthermore, it is necessary (in order for work to be done) that a displacement take place

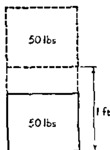


Fig 4 1 Fifty foot-pounds of work done in lifting fifty pounds one foot vertically upward

From the foregoing it is clear that holding up a wall or a ceiling all day long involves no work at all in the technical sense because no motion takes place, although the process may produce con-

siderable muscular fatigue Moreover, there would be no work involved at all in "pushing" a heavy trunk at constant speed along a perfectly smooth, frictionless (if such were possible) floor, owing to the fact that, in the absence of friction, the only forces acting on the trunk (i e, the pull of gravity and the upward push of the floor) act at right angles to the displacement See fig 4 2



Fig 4 2 If floor is frictionless no work is done moving trunk along at constant speed since no force is required

This means, of course, that it is impossible to *push* anything (at constant speed) along a frictionless surface Although this frictionless condition can never be wholly attained, it can be approximated as on slippery wax, or ice, etc, under which circumstances the force required is actually very small

Work, then, is a very special concept, whose importance may not even yet be appreciated It is measured in foot-pounds or dyne-centimeters One dyne-centimeter is called an *erg* It will be recalled that the dyne is a very small unit of force—namely, that required to give a gram of mass an acceleration of one centimeter per second per second

Energy—Kinetic and Potential. The capacity to do work is also an important concept This is called *energy* Any body capable of doing work is said to be endowed with energy, of which many varieties have been classified There is energy due to motion called *kinetic energy* See fig 4 3 This is the type of energy possessed by a moving automobile, as indicated by the damage which would result from a head on collision with another car It can be shown that kinetic energy is expressible as one-half the product of the mass and the second power of the velocity, but in the present development this relationship will not need to be emphasized

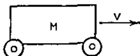


Fig 4 3 Kinetic energy is possessed by the car if it has a velocity

A boulder on the top of a cliff al o has energy because the

boulder, if released is capable of doing work as it crashes down the side of the cliff See fig 4 4 This is called *potential energy* In the grandfather clock, the weights are raised and potential energy is given to the clock by the person who winds it As this energy is released the weights gradually fall, the mechanism is kept in motion, and work is done Coal, fuel oil, and dynamite, as well as coiled springs and atomic bombs, also possess potential energy because they are all capable of doing work Thus this abstract capacity to do work becomes a very fundamental notion Indeed, it is a unique concept as we shall now see

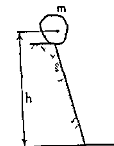


Fig 4 4 Boulder has potential energy with respect to lower level

Significance of the Energy Concept As one contemplates the concept of energy one realizes that it is in all reality a most comprehensive one, *for the entire physical world can be thought of as a world of energy* Potential energy stored up in the earth in the form of coal, oil etc by the sun—the source of all energy on this planet—is gradually transformed into the kinetic energy of motion, the chemical energy of plants and explosives, the energy of radio, electricity, light, sound, etc Indeed, each branch of physics may properly be said to be merely a different manifestation of energy

Conservation of Energy The concept of energy further provides a possible approach to the whole study of physics because of a very important principle This is the principle which states that *all the energy in the universe is conserved*, or that this universe can neither gain nor lose any of its capacity to do work This capacity can be transformed from one kind to another but not lost The implication is that energy takes on a sort of materialistic significance such that the various branches of physics merely represent different manifestations of it Nowhere can the store of energy be increased without a corresponding sacrifice elsewhere It must be remembered however, that energy really has no such material existence, certainly not in this discussion It is just a useful concept in terms of which certain explanations become possible, and about which the conservation principle provides the basis for a broad generalization The generalization is of

far reaching consequences and is on a par with Newton's laws of motion in order of importance Needless to say, it provides a very useful method of analysis for the theoretical physicist as well as the practical man who designs machinery, for machines do work, even if the amount of work done by a machine is often less important than the rate at which it is done

Power The rate at which work is done is called *power* A large machine can be said to be more powerful than a small one merely because it can do the same amount of work in less time than the small one It is to be noted that the power of a person, a *mechanical device, or an animal should not* in any way be confused with the amount of work capable of being done A race horse, for example, pulling a light buggy at a high rate of speed may do exactly the same amount of work in a given length of time as a draft horse pulling a heavy load rather slowly The commonly accepted unit of power is the *horsepower*, equal to 550 ft -lbs per second or 33 000 ft -lbs per minute

The significance of the power concept is clearly indicated by the present-day methods of paying for labor, i e, by the hour or by the job Everyone realizes that for manual labor a man is more valuable than a boy and hence is paid more per hour On the other hand, a boy working half as fast and receiving half as much pay per hour as the man may accomplish the same total amount of work and acquire the same total pay, but of course in twice the time Some jobs however, call for a faster rate of expenditure of energy than a man can provide, whereupon a more powerful device is required

Machines A machine is defined as a device for transmitting and (or) multiplying force By the use of a machine a large resisting force can often be overcome by the application of a much smaller effort force In view of the preceding discussion it is now easy to see how this is possible The amount of work required to be done on the machine is never less than the amount done by the machine—indeed it is always somewhat greater, because of friction—but, since work is the product of a force and a displacement, force can be reduced if the displacement is made correspondingly larger See fig 4 5 Thus the force can be halved if the displacement is doubled because the product of the two remains the same With a block and tackle for instance, it may be necessary t

out ten feet of rope to lift a load two feet See fig 4 6 Therefore, except for friction, it should be necessary in this case to exert only one-fifth as much force on the rope as would be re-

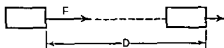


Fig 4.5 Work here is force F times displacement D W = F × D A smaller F acting through a larger D could produce the same answer

quired to lift the load directly In this manner *mechanical advantage*, defined as the ratio of the force overcome to the force applied, is acquired Sometimes a change in direction is the only advantage gained by a machine (see fig 4 7), but in all cases the product of the effort force multiplied by the distance through which its point of application is moved equals the product of the

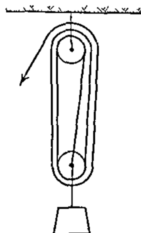


Fig 4 6 A block and tackle with an advantage of 5 times

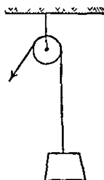


Fig 4 7 Only an advantage of direction is gained by this pulley

resistance force (including the resistance of friction) multiplied by its displacement, as a given amount of work is done

In the absence of friction the mechanical advantage can be determined merely by considering the relative distances through which the forces are exerted In fig 4 6 five feet of rope must be

pulled out of the tackle for every foot through which the load is lifted. This ratio, here equal to the number of strands connected to the movable pulley, is called the *theoretical mechanical advantage* as contrasted with the actual mechanical advantage, which is the ratio of the forces involved. The ratio of the actual to the theoretical advantage is the *efficiency* of the machine. For many purposes only the theoretical advantage is specified since this is readily determined by a consideration of the design of the device. In other words it is usually possible to figure out how far a certain point must be moved by an applied force compared to the distance covered by the resisting force without even operating the machine.

Other Examples of Machines. Another example of a machine is the *ordinary lever*. See fig. 4.8. It is obvious from the above discussion of the pulley that by means of a lever a large force can be overcome by the application of a smaller one because the smaller one acts through a larger distance. The so called law of the lever, which is readily derived from the law of conservation of energy, states that the force applied, multiplied by its lever arm (previously defined), equals the force overcome, multiplied by its lever arm. With a lever, very little work is required to overcome friction, i.e., the efficiency is relatively high, because the small contact surface between fulcrum and lever does not allow the friction force to operate through a large distance.


Fig. 4.8. The lever is a machine.

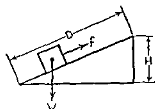


Fig. 4.9. The inclined plane. A small force f acting through a distance D replaces a larger force W acting through a smaller distance H.

The *inclined plane* also operates upon the same principle as the lever and the pulley. See fig. 4.9. With this device, advantage is taken of the fact that the hypotenuse of a right triangle, i.e., the longest side of the triangle exceeds the lengths of the other sides according to the size of the angles made between it and them. Thus a heavy load can be raised from the floor to a table by sliding it up a plank stretched from floor to table, making a so called inclined plane. The length of the incline being greater †

the elevation of the table, less force (except for friction) is required to push the body along the direction of the incline than to lift it directly Even if additional work is required to overcome the added friction introduced by lengthening the path over which the body is moved, the inclined plane often makes possible the raising of loads that would otherwise be impossible because of limitations such as are imposed by human strength

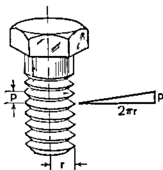


Fig 4 10 The screw is really a series of inclined planes of circumference $2\pi r$ and pitch P

A modification of the inclined plane is the *ordinary screw*, a thread of which can be imagined to be unwound so as to produce a wedge shaped figure which is nothing but an inclined plane See fig 4 10 A relatively small force may suffice to produce a complete twist of the screw, causing it to advance, by a distance known technically as the pitch, against considerable opposition Similarly a relatively weak force applied to the blunt edge of a wedge can produce a large force perpendicular to the face and thus huge logs can be readily split open by forcing wedges into them The wedge is simply an inclined plane

In each of the machines listed above (and many more could be

Friction The force of friction is a very important force in physics Although the engineer is often engaged in attempts to minimize its effects, as by the use of lubricants, to increase the efficiency of a machine, it is nevertheless an important and desirable factor in the daily lives of all Imagine how one would start even the most powerful or most expensive car upon a frictionless surface

Coefficient of Friction The force of friction is characterized by the fact that it always acts along the boundary surface between two bodies It is thus a tangential force and its magnitude is always proportional to the force pressing the two surfaces together See fig 4 11 The pull F due to the weight of the falling body just balances, and is therefore a measure of the force f of

friction when the body is caused to move at constant rate The proportionality factor is known as the *coefficient of friction*, which is technically defined, for any pair of surfaces, as the ratio

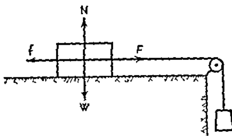


Fig 4 11 Friction force f is proportional to N, i.e., $\frac{F}{N}$ = constant (coefficient of friction)

of the tangential force of friction divided by the perpendicular force pressing the two together The force of friction does not, as is commonly thought, depend upon the area of the surface in contact The coefficient is of course different for different pairs of surfaces

Summary In the last two chapters we have seen how force and motion are intimately related We have considered the vector nature of force, a characteristic which is shared by many quantities in physics The vocabulary of motion has been developed to the point where it becomes possible to understand Newton's fundamental laws of motion The concepts of work and energy have been developed and the very fundamental principle of the conservation of energy is thus given meaning We also have seen how mechanical devices can be used to multiply force, and thus a better understanding of the operation of machines is had Work, energy, force, and motion comprise that portion of physics commonly called mechanics Even with this rather brief survey of these topics, limited almost to vocabulary considerations, the student should acquire a better appreciation of this phase of the physical world in which he lives

Note In addition to questions after each chapter, sets of "Review Questions" are introduced between groups of chapters These are of the "multiple choice" type each question is presented with several answers, only one of which is correct.

QUESTIONS

1 If a load is to be raised to a point 10 ft higher than would you prefer to carry it up a vertical ladder an inclined plane? Which requires the greater force? case will more work be required? Why?
2 How much work is required to push a 50-lb body 10 a horizontal frictionless plane at a constant velocity
3 What is meant by energy? Why is it important?
4 Why are coal and gasoline said to contain energy?
5 Explain how a force of 20 lbs can move a 200-lb incline which rises 1 ft in 10 ft if friction is
6 What is power? Is it possible for a so-called ' motor and a ' horsepower motor to do the same am work?
7 What is meant by the mechanical advantage of a m
8 Why is something which is hard to cut placed near of a pair of scissors?
9 Must a lever always be used so as to gain advantage or is a reduction in force sometimes advantageous?

REVIEW QUESTIONS

(See page 190 for answers)

Chapters I, II, III, and IV

1 A hypothesis is 1 a necessary step in inductive reasoning, 2 the same thing as a scientific theory, 3 always successful, 4 never successful, (5) not allowed in physics
2 Galileo 1 was the father of inductive science, 2 always reasoned deductively, 3 was a Greek scientist, 4 taught that heavy bodies fall faster than light ones, 5 lived in the nineteenth century
3 Physics is concerned with all of the following except 1 force, 2 motion, 3 logic, 4 sophistry, 5 relativity
4 The kilogram is the basic unit of 1 mass, 2 length, 3 time, 4 momentum 5 acceleration
5 Measurements in physics are 1 always precise, 2 usually indirect, 3 necessary to check theoretical speculation, 4 always made with micrometer calipers, 5 never made with micrometer calipers
6 The Greek period in physics is conspicuous because 1 of Galileo 2 Aristotle favored inductive reason

ing 3 the Greeks delighted in manual labor 4 *Arabic numbers had replaced* Roman numerals 5 of deductive reasoning ( )

7 Physics is primarily 1 an experimental science 2 a study in logic 3 an earth science 4 applied mathematics 5 engineering ( )

8 Modern physics 1 completely displaces Newtonian physics 2 is nothing but Einstein s relativity 3 started about 1800 4 explains why light is propagated 5 is more inclusive than Newtonian physics ( )

9 The British standard of length is 1 the foot 2 the yard 3 the inch 4 the centimeter 5 the meter ( )

10 A force 1 always keeps a body going in a straight line 2 can never point upward 3 is a ve tor quantity 4 is necessary to give a body constant motion 5 is a synonym for power ( )

11 The meter is 1 a unit of inertia 2 equal to three feet 3 a fraction of the earth s rotational period 4 ten times a decimeter 5 100 millimeters ( )

12 A force of 10 lbs exerted on a lever 10 ft from the fulcrum will overcome a load at 2 ft from the same fulcrum of 1 50 lbs 2 50 grams 3 200 ft. lbs 4 200 lbs 5 100 lbs ( )

13 The resultant of two forces of equal magnitude making an angle of 120° with each other is 1 a force of the same magnitude 2 a velocity of the same magnitude 3 a force whose magnitude is equal to the square root of the sum of the squares of the two forces 4 zero 5 a force at right angles to either one ( )

14 A velocity may change 1 only in two ways 2 in direction only 3 in magnitude and direction 4 only vertically 5 only by Newton s law ( )

15 The acceleration of gravity is 1 32 cm per sec per sec 2 32 ft per sec 3 32 ft per sec per sec 4 32 cm per sec 5 zero ( )

16 Galileo dropped a large body and a small body simultaneously from the top of the lean ng tower of

wa

3 1

ha

pieces of metal

17 Momentum is 1 mass times force, 2 force times velocity 3 force times distance, 4 mass times velocity, 5 mass times acceleration ( )

18 The Cavendish experiment refers to 1 the determination of centripetal force, 2 the conservation of momentum in a collision, 3 the gravitational attraction between bodies, 4 the constancy of the stretch of a spring to the force acting on it, 5 the determination of the acceleration of gravity by dropping a ball upon a pan pivoted to make pencil marks on a rotating drum ( )

19 A freely falling body falls in the first second 1 32 ft , 2 32 in , 3 980 cm 4 16 ft , 5 64 ft ( )

20 To keep a 10 lb body traveling with constant speed of 5 ft per sec in a straight line requires a force of 1 50 lbs , 2 10 lbs , 3 20 lbs , 4 2 lbs , 5 0 lbs ( )

21 Newton s second law of motion leads to the conclusion that 1 forces appear as twins, 2 all bodies are attracted toward the center of the earth, 3 force is mass times acceleration, 4 a body at rest continues at rest unless a force acts, 5 weight is the force of gravity ( )

22 Mass is the quantitative measure of (1) inertia, 2 gravity, 3 weight, 4 momentum 5 displacement ( )

23 Velocity has 1 force, 2 magnitude 3 displacement, 4 mass, 5 weight ( )

24 Galileo lived at about the time of 1 Aristotle, 2 Democritus 3 Plato, 4 Newton, 5 Maxwell ( )

25 A body traveling in a circle with constant speed 1 is accelerated 2 has constant velocity, 3 is not accelerated, 4 does not move, 5 is not affected by gravity ( )

26 If body A is projected horizontally at the same instant body B is dropped from the same point and if air resistance is neglected 1 B will reach the ground first 2 A will reach the ground first, 3 A will go farther than B, 4 A will have a smaller displacement than B, 5 the displacement of each is zero ( )

27 Acceleration is 1 the time-rate of displacement, 2 the rate at which distance is covered, 3 the time-rate of change of velocity, 4 the time-rate of

change of speed, 5 the time rate of change of force ( )

28 Work is measured in 1 ft-lbs, 2 horsepower, 3 grams, 4 ft-lbs per sec, 5 lbs ( )

29 Work is the product of force and distance 1 regardless of direction, 2 never, 3 when the two are mutually perpendicular, 4 when the two point in the same direction 5 only in the absence of friction ( )

30 The work done in moving a 10 lb body 5 ft horizontally on a frictionless surface is 1 10 ft-lbs, 2 500 ft-lbs 3 zero 4 50 ft-lbs, 5 500 lb ft ( )

31 The work done when a 50 lb body is lifted 10 ft vertically is 1 500 ft-lbs, 2 zero, 3 500 joules, 4 250 ft-lbs, 5 32 ft lbs ( )

32 The capacity to do work is called 1 power, 2 energy 3 mechanical advantage, 4 momentum, 5 efficiency ( )

33 A 2 horsepower machine necessarily 1 can do twice as much work, 2 works twice as fast 3 expends twice as much energy 4 expends four times as much energy 5 works just as fast as a 1 horsepower machine ( )

34 A 138 lb man climbing a flight of stairs 20 ft high in 20 seconds displays approximately 1 125 H P, 2 one-half H.P 3 one quarter H P 4 138 ft-lbs per minute 5 one H P ( )

35 If the velocity of a body is doubled 1 the kinetic energy is quadrupled 2 the kinetic energy is halved 3 the potential energy is doubled, 4 the potential energy is halved, 5 the kinetic energy is unchanged ( )

36 By the use of an inclined plane to raise a heavy body up onto an elevated bench 1 more work is probably done 2 less work is probably done, 3 more force is required, 4 the same work is probably done 5 the same force is probably required than without the use of the inclined plane ( )

37 The mechanical advantage of any machine is 1 the ratio of the force overcome to the force applied, 2 the same as the efficiency of the device, *3 the ratio of the force applied to the force overcome*, 4 always two, 5 always zero ( )

tion is called *simple harmonic motion* See fig 5.3 The in tance of this kind of motion lies in the fact that it is pro whenever a distortion of an elastic body is released an resultant vibration takes place in a str line There are more complicated ty vibrations, of course, but all straight-li brations of small amplitude are simple monic to a first approximation

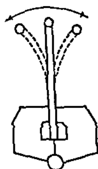


Fig 5.3 Strip of iron in a vise Another example of simple harmonic motion

Characteristics of Vibratory Mo A simple harmonic vibration, being a odic motion, is often specified by it *quency*, defined technically as the num complete vibrations which take place i second of time Thus if a boy on a s board jumps up and down two time second, his frequency of vibration is vibrations per second This is equivale saying that one-half second is require one vibration The length of time required for a single vibr is known as the *period* of vibration The period, then, is th ciprocal of the frequency, i e, it is unity divided by the quency These two concepts, frequency and period, provid means by which vibratory motions are usually specified in a q titative manner The *amplitude* of a vibration is the maxi displacement measured from the equilibrium position, and i to be confused with the total to-and-fro swing, which is twic amplitude

Resonance All bodies have natural periods, or frequen of vibration depending upon their masses, their geometric c acteristics, and the manner in which they are set into vibra Because of this fact the phenomenon of *resonance* is import A body is found to be set into vibration very readily when a f acts upon it periodically with the body's natural frequency child readily learns how to "pump" a swing, i e, he learns he can give the swing a vibration of considerable amplitude i properly times his impulses in accord with the natural perio the swing The diver on the springboard also learns how to t advantage of the natural frequency of the diving board to incre his initial velocity

Resonance effects are sometimes undesirable and are then t

avoided Frequently it is observed that at certain speeds a car vibrates more readily than at other speeds This is due to a coincidence of the vibration frequency produced by irregularities in the road and that produced by the rotating motor Two vibrations with the same frequency are said to be in *phase* with each other if both start out together Resonance occurs when two similar vibrations are in phase with each other and does not occur when they are out of phase

The Simple Pendulum Another vibratory motion closely resembling simple harmonic motion is the motion of the simple pendulum This is simply a small bob suspended by a relatively long flexible cord and set into to-and fro motion See fig 5 4 The interesting characteristics of pendulum motion were supposedly discovered in the scientific sense by Galileo He found that the period of vibration of a pendulum depends upon its length and the acceleration of gravity at the place where it is located Although this is not a direct proportionality the relationship is relatively simple He also discovered that the period is the same whatever the amplitude of the swing providing it is not very large The pendulum of the grandfather clock although not technically a simple pendulum illustrates these characteristics The student can readily infer and correctly so that one method of determining the acceleration of gravity at a given place is to measure (rather precisely of course) the period of a simple pendulum This method is employed by the United States Coast and Geodetic Survey which keeps the scientific world posted with such information at specified locations on the earth s surface



Fig 5 4 The simple pendulum

The Study of Liquids a Branch of Elasticity Before going on to a further consideration of vibrations and their effects on matter as a consequence of its elastic properties a strictly logical presentation of the phenomena of physics requires that we stop here to allow for the study of another group of phenomena which result from considerations of elasticity namely liquid phenomena Elasticity was defined as the ability of matter to recover from distortion If one were to list various types of distortion such a list would include simple stretch linear compression over all compression or expansion and twists or shears See fig 5 5 T

last of these types, the shear, in which the force is applied tangentially to the surface, plays an important role in physics in that it provides a means of classifying matter

Matter is readily classified into two main divisions called *solids* and *fluids* according to whether or not resistance is offered to a

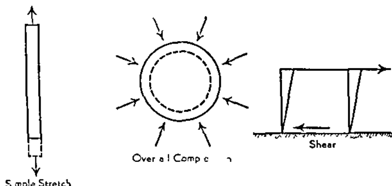


Fig 5.5 Various types of distortions.

shearing type of force Although it is all relative and a sharp distinction is not possible in every case, the general classification is useful The significance of this is that a fluid will not withstand a transverse force Also, it is impossible to twist a column of fluid For convenience, fluids are subdivided into two groups, *liquids* and *gases*, depending upon whether or not they display a free surface Thus a jar can be only half full of water, but with a gas it is different If the jar contains nothing but air it is always com-



Fig 5.6 A container partly full of a liquid displays a free surface but a gas always completely fills its container

pletely full, whether it contains a little or a lot, because the air displays no free surface See fig 5.6

Now it is clear that the study of liquids at rest—*hydrostatics*—exemplified by water in free ponds, open columns, wells, test

tubes, etc , involves only the action of gravity upon the liquid as a whole, i e , a simple external force, and does not involve internal forces of the shearing type, because only forces perpendicular to the surface of a liquid can be applied Thus a free liquid surface is called level because it is perpendicular to the plumb line, which is, strictly speaking, merely the direction of the pull of gravity

Density The study of fluids requires special vocabulary The concept of density, although not restricted to fluid considerations, is all important to the logical development of this branch of physics because it is one of those concepts in terms of which *others are derived* The layman is more or less familiar with the term density and generally speaking, uses it to differentiate between more and less massive substances For example, a marked distinction between lead and aluminum in terms of mass is readily appreciated, but the technical definition of *density* as mass per unit volume is not such a common notion See fig 5 7 Density

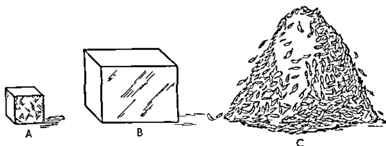


Fig 57 A pound of (A) lead (B) aluminum (C) feathers illustrating differences in density

is defined as the ratio of the mass of a body divided by its volume (grams per cubic centimeter) i e it is mass per unit volume The distinction between weight and mass again comes up Although density is correctly expressible in pounds per cubic *foot* (mass pounds) *it is not correct to* refer to it as weight per unit volume in spite of loose practice on the part of many tech nical people Not that weight per unit volume is an undesirable concept, it simply is not density Sometimes this is referred to as *weight density* Again we note that strictly logical thinking often requires painfully precise definitions and careful usage, without which false conclusions may be reached

Specific Gravity. The term "specific gravity" is also a term heard quite frequently today Car owners are often concerned with the specific gravity readings of their storage batteries What does the term mean? Technically the *specific gravity* of a substance is defined as the ratio of the density of the substance divided by the density of water It provides a way of expressing the relative mass of a certain volume of the substance with respect to the same volume of water Specific gravity, then, is just a number

Fluid Pressure The concept of fluid pressure, already mentioned, will be considered next Because no shearing force can be exerted on a fluid, it follows that the only force which can be exerted on a fluid must be directed perpendicularly against its surface Recall the reference to the sailboat in the chapter on forces Thus the walls of a fluid container push against the fluid, but only perpendicularly Furthermore, the total force so impressed obviously depends upon the total area upon which it acts In terms of the perpendicular force per unit area, such a total force is given by multiplying it by the number of units of area This force per unit area perpendicular to the surface is designated as *fluid pressure* Thus it makes sense to state that the pressure in a given water main is 80 lbs per square inch, meaning that upon each and every square inch of surface 80 lbs is acting regardless of the size of the pipe An interesting consequence of this is the not so easily realized conclusion that a force of a mere fraction of a pound may suffice to stop a leak if the cross-section area of the leak is only a small fraction of a square inch Thus a very careful distinction must be made between the concepts of pressure and total force if one is to reason intelligently about these matters

It can be further shown that pressure at a point below the surface of a given fluid depends upon the depth of the fluid This of course makes it very easy to calculate the pressure of water at the base of a standpipe, for example Moreover, since the pressure at a given place thus depends only on the depth, it follows that in two open vessels communicating with each other at the bottom and containing the same liquid, the level of the liquid in one will be the same as in the other This is because the pressure at the bottom where they communicate with each other cannot have two different values, as would be required if the levels were different Thus liquids are said to seek their own level under these circum

stances See fig 5.8 For this reason people often find it necessary to install cellar pumps in houses if the water level in the land about the houses is higher than the basement floors.

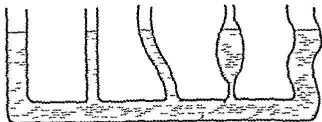
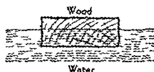
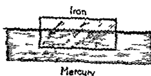


Fig 5.8. A liquid "seeks its own level" in communicating vessels regardless of the shape of the containers.

Buoyancy It is a common experience that bodies with specific gravities less in magnitude than unity, i e, with fractional specific gravities, float rather than sink in water See fig 5.9 This brings out an important concept called *buoyancy*, with which the fundamental principle of Archimedes is concerned When a body is immersed either wholly or partly in a fluid, obviously a certain amount of fluid is displaced From a consideration of the pressure which the fluid exerts on the body it follows that



Wood floats in water Its density is less than that of water



Iron also floats in mercury

Fig 5.9

the net effect of the pressure forces is a resultant force upward

fore, if the weight of a body is less than the weight of the fluid which it would displace if submerged, the body will float in the fluid, and vice versa, if it is heavier than the same volume of the fluid it will sink *Archimedes' Principle* is the formal statement of this thoroughly tested conclusion It states that all bodies com-

pletely or partially immersed in a fluid find themselves buoyed up by a force equal to the weight of the fluid displaced The principle explains the action of the floating type of hydrometer universally

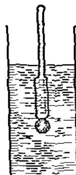
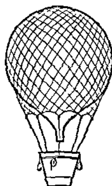


Fig 5 10 A hydrometer to measure the specific gravity of a liquid

used in garages to determine the specific gravity of automobile batteries A bob either floats up to a certain mark or it does not, depending upon the specific gravity of the solution in which it is floated See fig 5 10 Thus the degree of electrical charge in the battery is determined because it depends upon the specific gravity of the solution

Gases According to the definition already given, gases are fluids and so it should, and does, follow that the foregoing applies to the ocean of air which surrounds the earth and constitutes our atmosphere Air has mass and therefore density Balloons are buoyed up in air in accordance with Archimedes' principle just as ships are buoyed up in water See fig 5 11 By changing the ballast a balloon can be made to rise or fall at will just as a submarine can be made to rise or sink in water



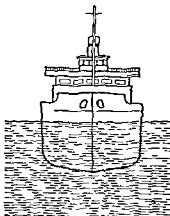


Fig 5 11 Balloons are buoyed up by the air just as ships are buoyed up by water

Atmosphere Pressure and the Barometer The earth's surface is at the base of the atmosphere and hence a hydrostatic

pressure exists due to the weight of the air This so-called atmospheric pressure amounts to approximately 15 lbs per square inch and is readily measured by the various types of barometers available today One can appreciate the magnitude of atmospheric pressure by the following experiment A slender glass tube some three feet long is filled with liquid mercury The top is then closed by holding one s thumb over the exposed end If now the tube is inverted and the end which is closed by the thumb is immersed in a dish of mercury, it is found upon removing the thumb that the mercury does not all run out of the tube See fig 5 12 A column some 30 inches high remains in the tube with a vacuum above it Thus it is seen that the pressure at the bottom which can be thought of as the place where a tube of mercury communicates with a vessel of air (the whole atmosphere) is just that which exists at a point 30 inches below the surface of mercury, a liquid whose density is between thirteen and fourteen times that of water Thirty inches of mercury corresponds to approximately thirty four feet of water, and so lift pumps can raise water up out of a well not more than thirty four feet This is because the action of the pump is merely to remove the air from the pipe above the water until the atmospheric pressure forces the water up to take its place

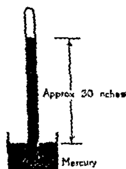


Fig 5 12 Barometric column

Measurement of Altitude The pressure of the atmosphere varies slightly from time to time—almost continuously—due to variations in meteorological conditions Many predictions of weather are based to a large extent upon barometric pressure Altitude can also be measured by the barometer because the pressure decreases with altitude This is obvious in view of the fact that at high altitudes the air above a given point weighs less than that above a point at lower altitude there being less of it in the former case The aviator utilizes this principle to measure his elevation The height of Mt Katahdin, the highest mountain in Maine, was first measured by observing the drop in a mercury barometer as it was carried from the base to the summit of th mountain.

Pascal's Principle. Going back to the discussion of liquid pressure, *another interesting consequence follows from fundamental considerations* If two vertical tubes of different cross section are joined together and are partially filled with a liquid so as to leave two open surfaces of different sizes at approximately the same level, then the application of additional pressure to one

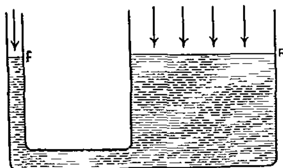


Fig 5 13 Pascal's Principle A small force f act- ... able to balance ... larger cross ... ators, barber chairs, etc

side is transmitted without loss to the other See fig 5 13 This is known as *Pascal's Principle* This principle is utilized in the operation of many practical devices, including the hydraulic brakes on the modern automobile

As a consequence of the pressure transmission without loss, the total force on the small surface in fig 5 13 is proportional to the total force on the large surface in just the same ratio as the areas themselves Thus a 10-lb force on a 1-inch area is multiplied to 100 lbs on a 10 inch area because of Pascal's principle, the force per unit area being *the same in each case*

Applications of this principle should be obvious The hydraulic press acts because of its two cylinders of unequal area connected together In the case of the automobile brake pedal, which creates a certain pressure in a tube of brake fluid, the pressure is transmitted through the pipe line to the brake drums in the wheels, where it acts upon pistons of larger area to create large br[illegible] forces The hydraulic elevator and the hydraulic lift at modern filling stations represent further applications of the same principle

Summary In this chapter we have seen that matter displays elasticity This property accounts for vibratory motions such as are exemplified by springs of all kinds Simple harmonic motion is the simplest type of vibratory motion Matter is divided into two classes, solid and fluid, according to its elastic characteristics Liquids and gases are both fluids Fluids display several unique properties such as buoyancy, pressure transmissibility, etc Archimedes' principle gives the relation between buoyancy and fluid displacement The atmosphere is a fluid which exerts a pressure on all bodies This is measured by the barometric column, which is also utilized in measuring altitude Pascal's principle accounts for the operation of many machines such as elevators and hydraulic automobile brakes Thus it is seen that the study of fluids is a very important part of the study of physics

QUESTIONS

1 What is meant by elasticity?
2 Would you say rubber is more or less elastic than steel? Why?
3 Describe the operation of the spring balance
4 Distinguish between stress and strain
5 What is meant by the period of a vibration?
6 What is the amplitude of vibration?
7 How does the period of vibration of an automobile change when an additional load is placed on it?
8 Describe how the acceleration of gravity might be measured by means of a simple pendulum
9 What is the technical distinction between a solid and a fluid?
10 Why is water said to seek its own level?
11 How does the "suction" pump really work?
12 Is a "suction" pump suitable for pumping water from a level 37 feet below the surface of the ground? Why? Explain
13 Is the reading of a barometer affected by carrying the instrument up a mountain providing the temperature is left constant?
14 What is Pascal's principle? Give an illustration
15 Why does an oil leak in one brake of a hydraulic brake-equipped automobile ruin the braking action of all four brakes?

CHAPTER VI

WAVES AND SOUND

All the topics thus far discussed under the general heading of elasticity, including the topic of fluids at rest, are commonly grouped under the heading Statics of Elasticity—a branch of the Mechanics of Deformable Bodies When deformations are propagated through matter, so-called *elastic waves* are produced and their study is properly referred to as the study of Dynamics of Elasticity

Fundamental Wave Concepts It is a common observation that deformations may be transmitted through material media A small distortion, such as a localized compression or a transverse shear, readily passes along the whole length of a long coiled spring See fig 6 1 Moreover, everyone realizes that a



Fig 6 1 A compression will travel along a coiled spring

stone dropped into a still pond produces first a depression in the water and then a succession of circular mounds and depressions which spread out and radiate over the entire surface of the pond, moving outward from the central point of disturbance with a definite speed See fig 6 2 This phenomenon is called wave

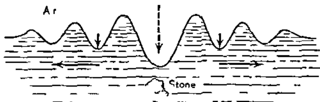


Fig 6 2 Cross section of the circular mounds and de- pressions propagated from the point where a stone into a pond The medium just vibrates about i position

motion Technically, *wave motion* is defined as the propagation of deformations through a deformable medium It is usually a periodic disturbance and is produced by a vibrating source The medium is set into a succession of vibrations, each specific part moving back and forth about its own point of equilibrium, but the disturbance travels It should be noted carefully that the medium itself does not travel Indeed, it is more accurate to say that only energy travels

Wave Characteristics. Waves have numerous characteristics The speed of a wave is a very definite matter By means of a stop watch one can readily time the passage of a given wave across a known distance and therefore determine the velocity of the wave as it radiates out from its origin The distance between two successive wave crests, or between two successive wave troughs, or more generally between two successive similar configurations, is referred to as the length of the wave or the *wave length* See fig 6 3

A traveling train of waves also has a *frequency*, i e, the number of crests that pass a given point per second Obviously the following relation holds the distance between two successive crests (wave length) multiplied by the number of crests per second (frequency) just exactly equals the velocity of the wave

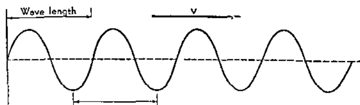


Fig 6.3 Velocity equals wave length times frequency

motion This is probably the most fundamental of all wave relationships It is also obvious that the frequency of the wave motion is just the same as the frequency of the disturbance producing it For example, a vibrating reed sets up a wave motion in the medium in which it is located, such as air, with a frequency just equal to the number of times it makes a complete vibration per second It is also a fact that the length of the wave thus produced depends upon the elastic characteristics of the medium, such as the density and the stiffness, etc This is usually expressed

in terms of the velocity, which, as has just been shown, depends directly upon the frequency and the wave length

Another fundamental concept is the *amplitude* of a wave, defined as the maximum displacement from the equilibrium position See fig 6 3 again

Types of Waves Waves can be classified according to type There are *transverse waves* such as the ripples just mentioned when a stone is dropped into a still pond These are characterized by the fact that the displacements of the medium are always perpendicular to the direction of propagation (the surface of the water moves up and down as the wave progresses horizontally) There are also *longitudinal waves* in which the displacements are always back and forth parallel to the direction of propagation Waves such as sound waves in air are of this type Compressions and rarefactions of the medium pass along in a direction parallel to themselves These are the two most common types and the ones to which elementary discussions are usually limited, but torsional, circular, spherical, and ellipsoidal waves, just to mention a few, are considered in more advanced treatises

Representation of Waves The waves produced by pure simple harmonic disturbances are technically known as sine waves, and are readily represented by the familiar "wavy line"

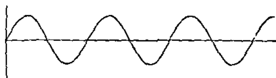


Fig 6 4 All waves can be represented diagrammatically by the simple wave picture

Although it should be remembered that waves do not have to be as simple as these, nevertheless waves in general can be represented diagrammatically by the simple wave picture See fig 6 4

Interference of Waves The wave picture affords, among other things, a simple means of representing the superposition of waves, a common phenomenon When two waves are superimposed (as for example two water waves) the result depends upon conditions If the two similar waves of equal amplitude are in phase, i e, if crest coincides with crest and trough with trough, the result is a reinforced wave of twice the amplitude of either

On the other hand, the result is complete nullification of both if the two waves happen to be just out of phase, i.e., if the crest of one coincides with the trough of the other. There may also be con-

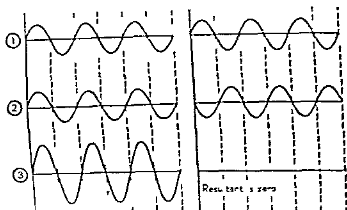


Fig 6.5 Constructive and destructive interference of waves. The waves in part 3 represent the resultants of those in 1 and 2

ditions in between complete reinforcement and complete nullification. This general phenomenon is referred to as *interference*, and includes both constructive and destructive types. See fig. 6.5

Beats. As may be inferred, interference phenomena play a very important role in the study of waves. When two continuous waves of slightly different frequencies are superimposed the result is an alternation of constructive and destructive interference

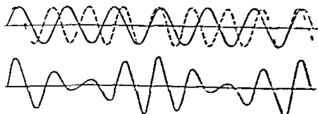


Fig 6.6 Beats are produced by two waves of almost the same frequency coming into phase with each other every once in a while

known as the *beat* phenomenon, whose frequency is exactly equal to the difference between the two original frequencies. See fig. 6.6. This is easily appreciated in the case of sound waves by striking two tuning forks of nearly, but not exactly, the same frequency

Reflection of Waves Waves are *reflected* at boundaries between media Just as a tennis ball can be bounced up from the ground, i e, reflected, so can water waves be reflected from an obstruction back into the medium in which they originated A complete analysis of the phenomenon is not possible here, but suffice it to say that it involves chiefly a further study of the elastic properties of matter

Refraction of Waves The changing of speed as a wave passes from one medium to another is technically known as *refraction* See fig 6 7 This is another important concept which we shall run across later, particularly in the study of optics

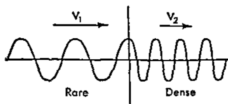


Fig 6 7 Refraction of waves Waves may undergo a change in velocity—i e be refracted—as they pass from one medium to another Going from a rare medium to a denser one they are slowed up and the wave length is decreased

Standing Waves When a wave traveling in one direction in a given medium interferes with a wave of the same length traveling with the same speed but in the opposite direction, an interesting situation develops The result is a wave motion of a very unique type Every portion of the resulting vibration passes through the equilibrium position at the same instant There are certain points in the vibrating medium which are always in equilibrium and other points where the disturbance is a maximum The pattern is called a *standing wave* pattern because the waves do not progress They are stationary The points of minimum disturbance are called *nodal points* or *nodes*, and the points of maximum disturbance are called *antinodes* or *loops* See fig 6 8 This condition is realized when a wave passing along a medium meets its own reflection coming back with the same speed and wave length from a boundary Obviously resonance effects are readily appreciated under these circumstances when the phase

relationships are favorable Owing to the existence of the natural vibration frequencies already mentioned, standing waves are readily set up in bodies Thus it is natural for a violin string fixed at either end to vibrate in a standing wave pattern with a loop

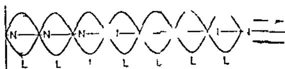


Fig 6.8 The nodes and loops of standing waves produced by two waves of the same length and amplitude but traveling in opposite directions at the same time

at the center and with nodes at the ends Similarly it is easy to make a column of air in a pipe, open at each end, assume a standing wave pattern with loops at either end and a node at the center

Overtones As a matter of fact, there are many natural modes of vibration for a string or an air column or for any body at all Whereas it is natural for a string, such as a violin string fixed at each end to vibrate with a loop at the center i e as a single segment, it is also natural for it to vibrate in two segments with a third node at the center Moreover, vibrations in three or more segments are possible Indeed, it is possible for such a

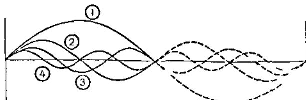


Fig 6.9 A string vibrating in (1) one segment (2) two segments (3) three segments (4) four segments—i e in its fundamental and 1st 2nd and 3rd overtone frequencies

string or air column to vibrate in any integral number of segments See fig 6.9 These various modes are referred to as over- *tone vibrations* with respect to the single segment type called the fundamental mode The length of the wave of the first over- tone in question is obviously just twice the length of the s

frequency is decreased and the wave length is increased as th source and the observer recede from each other In the case of sound, the result is a lowering of pitch in the latter case and a rise in pitch in the former This principle, when applied to light waves, gives the astronomer the remarkable power of determin-

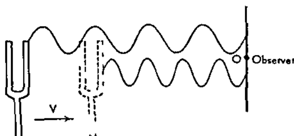


Fig 6 13 Doppler's Principle As the fork moves to the right with the velocity V the waves are crowded and appear to arrive at O with a greater frequency than otherwise

ing the speeds of certain stars and planets when their motion is directed toward or away from the earth It is obvious that tele- scopic means alone are insufficient to supply this information except when the motion is across the sky, i e, perpendicular to the line of sight

Sound as a Wave Phenomenon Numerous references have been made to acoustical phenomena in this discussion of waves This is because sound is one of the most common of all the wave phenomena Sound is nothing but a wave motion in ma (usually air) of a purely mechanical type Although it is thought to be restricted to those elastic vibrations capable o stimulating the sense of hearing, there is no particular reason for such a restriction In a more general sense, the term "sound" applies to any and all elastic waves in matter Today the field of *supersonics is recognized* This is a field in which vibrations above the audible range are considered The human ear is restricted, in its ability to recognize sounds, to a range of frequencies approximately 20 and 20 000 vibrations per second Thus an au dible sound is recognized when anything vibrates with a suitab intensity and frequency within these limits in a medium capable of supporting the vibrations and propagating them Pulses of air suffice to produce sounds regardless of how they are produced,

whether by an intermittent blast as through holes in a rotating disk or by the vibration of reeds, bells, air columns, strings, or

mer may readily be seen to vibrate if the whole device is mounted in a transparent exhausted glass container The velocity of sound in air is approximately 1100 feet per second

Characteristics of Sounds Sounds are recognized by three characteristics—loudness, pitch, and quality

LOUDNESS Loudness is a function of the intensity of the disturbance The volume control on a radio governs the loudness of the sounds emitted and, if the set is properly designed, affects no other characteristic

PITCH Pitch is the auditory effect of the frequency of the sound The human ear is capable of detecting slight changes in pitch Pitch is a characteristic by which high notes are distinguished from low notes on a musical instrument A range of frequencies in which the frequency is doubled is called an *octave* Thus we have several octaves on the standard piano keyboard such as, for example, the range from middle C approximately (256 vibrations per second) to upper C approximately (512 vibrations per second), which constitutes a single octave Actually this scale is an old one On the modern piano this range is from about 261 to 523 vibrations per second It is the pitch of a note which is affected by relative approach or recession of source and observer according to Doppler's principle already mentioned It is sometimes difficult to distinguish between the effect of pitch and loudness upon the human ear The lower limit of loudness capable of being detected by the average ear, or the threshold of hearing, varies considerably with the pitch of the note, as has been shown in recent years by experiments at the Bell Telephone Laboratories in New York City, a higher intensity being required for the lower frequencies than for the higher ones

There is a slight discrepancy between the musician's standard of pitch and that of the scientist Whereas 256 vibrations per second has been recognized as middle C by scientific workers, the musicians favor 440 as A above middle C This is somewhat different from the 427 which would be required on the scientific scale, and also means that the musician's middle C is 261

tions per second instead of 256 As a matter of fact, it is fairly generally agreed that 440 for A is universal musical practice today

QUALITY The quality of a sound is determined by the existence of overtones This means that if it were not for the difference in overtone patterns, a given note would sound just the same when played on the piano, the violin, the cornet, or any other musical instrument Stripped of their overtones, the same notes played on these several instruments would be indistinguishable and furthermore such pure notes would lack all semblance of quality Thus the only reason why a genuine Stradivarius violin may produce more pleasing notes than an imitation instrument is the difference in overtone patterns resulting from the elastic properties of the materials used in construction and from the construction itself Tuning forks usually produce very pure notes i e vibrations consisting almost entirely of fundamental vibration modes completely free from overtones and for this reason they are often used in the laboratories for standards of pitch

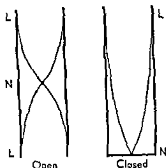


Fig 6 14 The fundamental wave length of an open pipe is twice the length of the pipe whereas the fundamental wave length of a pipe closed at one end is four times the length of the pipe

Standing Waves in Pipes Vibrating air columns have the interesting characteristic that when produced in pipes closed at one end and open at the other they lack all the overtones corresponding to the odd integers considering the fundamental as the zero overtone Pipes open at both ends are not so restricted in overtone possibilities See fig 6 14 Thus it is fair to say that so called open organ pipes are richer in quality than so called closed organ pipes See fig 6 15

Analysis of Sounds The quality of a musical note can readily be determined by the use of instruments which are capable of detecting all the various components in a complicated sound The trained ear can of course do this to a certain extent as is evidenced by the manner in which the various instruments can be detected in a symphony orchestra but electrical apparatus ha

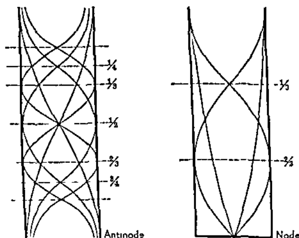


Fig 6 15 An open pipe (one open at each end) can have twice as many harmonic overtones as a closed pipe

as many

been developed which can do this more satisfactorily than the average ear

Summary We have seen in this chapter that the whole physical side of music is in reality a branch of physics We have considered the subject of sound as a part of the more general subject of vibrations and their associated waves as fundamental concepts in this descriptive survey of physics It has been found that these concepts are just as logically organized and interrelated as the concepts of force, mass, energy, etc , discussed in earlier chapters Again it has been shown that physics is a highly organized and logically developed science, to understand which the student must acquire a special vocabulary and use it with utmost precision

QUESTIONS

1 What is meant by sound?
2 Does the frequency of a sound influence the speed at which the sound travels? Do the high-frequency notes of a distant orchestra reach you before the low-frequency notes of the same chords?

3 Is there any part of a gong which remains stationary while it is sounding?
4 Note some of the factors that influence the quality of a sound
5 Which one of the three factors—pitch, loudness, and quality—enables one to distinguish one orchestral instrument from another?
6 What happens when two sound waves of the same frequency meet out of phase? What is the result if they meet in phase?
7. What happens when two sound waves of slightly different frequencies are combined?
8 As a violinist tightens a string on his instrument is he increasing or decreasing the pitch?
9 Does the loudness of the sound from a tuning fork increase when the fork is set on a table top? Why?
10 Explain the formation of an echo
11 A fork produces a frequency of 1000 vibrations per second What could be the frequencies of a second fork which, combined with the first, would give a beat frequency of 5 beats per second?
12 How may sound waves be produced?
13 How is sound energy transferred?
14 After a flash of lightning, thunder may not be heard for several seconds Why?
15 How does the sound from an open organ pipe differ from that from a closed pipe?
16 A whistle is blown and after 3 seconds an echo is reflected from a cliff How far away is the cliff?
17 Are sound waves of the order of magnitude of inches, feet, miles, or millimeters in length?
18 The acoustics of a room filled with people are better than those of an empty room Explain
19 Can there be too much absorption of sound in a room or auditorium from the point of view of good acoustics?
20 What is meant by the threshold of hearing? Does this threshold vary for different frequencies? The ear is most sensitive to what range of frequencies?
21 Define or state what is meant by "wave motion" and "elasticity"
22 What is meant by the terms "standing wave," "node," "antinode"?
23 What are "beats"?

CHAPTER VII

MATERIAL CONSIDERATIONS

CONSTITUTION OF MATTER PROPERTIES OF GASES SURFACE EFFECTS

One cannot proceed very far today in the study of the physical world, i e, the study of physics, without a consideration of the structure of matter Although, to some, this appears to be the realm of the chemist, it is well known to the initiated that there is no sharp boundary between the fields of chemistry and physics This is due in large measure to the fact that the chemist and the physicist working together have, in the last 50 to 75 years, made considerable progress in their attempts to unravel the mysteries of matter Only by the use of the physicist's tools, such as the spectroscope, the X ray, the electron tube, the mass spectrograph, the high-voltage generator, and others too specialized to mention here, has the chemistry of matter advanced to its present stage Chemistry has also furthered the knowledge of many physical properties of matter Physics and chemistry together, therefore, have developed theories of the structure of matter around the concepts of molecules, atoms, electrons, protons, and numerous other particles in a continuous state of motion

Molecules and Atoms. Present-day belief is based on the assumption that all bodies are built up out of *molecules* which are defined as the smallest known units of given chemical sub stances It furthermore seems evident that molecules themselves are built up out of smaller component units called *atoms* In t

units As recently as fifty years ago science accepted the view that the atom was an indivisible entity—hence the name 'atom'—but since that time knowledge pertaining to the structure of matter has increased enormously It seems certain today that the atom

has an internal structure of its own Starting with researches during the very last part of the last century and running all through the present one, the view has become scientifically substantiated that atoms are made up to a large extent of charges of electricity A very consistent theory was presented in 1913 by the Danish physicist Bohr, who pictured the atom as a miniature solar system with units of negative electricity revolving about a central, predominantly positively charged nucleus in a more or less elliptical orbit, as the planets revolve about the sun See fig 7 1 Although this theory is considered outmoded today, many of its features are still retained by contemporary physicists

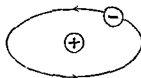
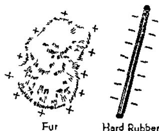
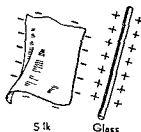


Fig 7 1 Bohr s conception of the hydrogen atom consisting of a negatively charged electron revolving in an elliptical orbit about a positively charged nucleus (proton)

Positive and Negative Charge The terms positive and negative as used in connection with electricity merely indicate a distinction between two opposite types of electrical charge as determined by the forces which they exert upon other charges, either attractive or repulsive When, for example, a glass rod is rubbed with a piece of silk, or when a piece of hard rubber is rubbed with fur, each of these objects acquires the peculiar property of attracting small bits of paper or other very light objects



Hard rubber rubbed with fur becomes charged thus



Glass rubbed with silk becomes charged thus

Fig 7 2

to itself This strange force is called an *electrical force* and is attributed to the existence of electrical charge The glass and the silk act differently, however, and a similar difference is noted between the rubber and the fur, as though one of each pair ex-

hibited an excess and the other a deficiency of this stuff called electricity The distinction was originally indicated by supposing two kinds of electricity called positive and negative just for convenience See fig 7 2 But since most electrical manifestations are readily accounted for by supposing the existence of merely a single kind of electricity and considering excesses of it as producing one effect and deficiencies of it as producing the opposite effect, it is not necessary to suppose that two kinds of electricity really exist The details of these considerations, however, will have to wait for a later chapter on electricity

Building Blocks of Matter—Electron, Proton, Neutron, Positron. The smallest unit of so called negative electricity known to exist is the *electron* (negative) The smallest positive charge is called the *proton* Bohr's theory suggested that for the *simplest known substance, namely hydrogen, the atom consists* of simply a proton serving as a nucleus and an electron revolving about it, just as the moon revolves about the earth, in a fixed orbit See fig 7 1 The other atoms are similarly constituted but are more complicated, the number of electrons in the various orbits and the constitution of the nucleus varying as the atom increases in complexity from helium, the second substance in the system, to uranium and plutonium, the most complicated This picture is somewhat out of date already in view of the tremendous rate at which research is being carried on in the universities and other scientific laboratories, but some of its features are still retained by those who require mental pictures for explanations since the newest theories are mostly mathematical in nature Recent discoveries include the *neutron*, a neutral particle, and the positively charged electron, the *positron*, so that the building blocks of the atoms are no longer restricted to two in number as was thought for so many years since 1890 or thereabouts At present it seems quite certain that even the nuclei of atoms have structure, so that whereas only a few years ago the atom was considered the ultimately small and indivisible unit of matter its structure and the components of its components now concern the physicist and chemist Such considerations, however, along with the release of atomic energy and the atomic bomb of 1945 must wait for a later chapter

Brownian Motion Thus we see that matter is made up of molecules, atoms, electrons, etc , but more important still for the

immediate discussion is the fact that these particles are in a state of incessant motion We live in a kinetic world, i e, a world of motion An indication of this is given by the observation of the so called *Brownian motion* This is the continuous agitation which one can see by examining, under the microscope, a sample of water in which fine particles of pulverized carbon are held

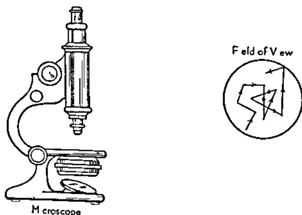


Fig 7.3 Particles viewed under the microscope are observed to be in a state of agitation The phenomenon is called Brownian motion

in suspension because they will not dissolve Tiny specks of carbon will be seen under these circumstances to be darting about in a most haphazard manner The phenomenon was first observed by the English botanist Brown, after whom it was named See fig 7 3 It is explained by bombardment of the carbon particles by molecules of the water As they strike they give rise to the irregular, haphazard motion of the particles which is observable through the microscope The molecules themselves are much too small to be visible, being only a few hundred millionths of a centimeter in size They would have to be many thousands of times larger to be visible through even the most powerful microscope available

Kinetic Theory of Matter This simple postulate has grown into a theory of sizable proportions commonly known as the *kinetic theory* To a first approximation it is assumed that molecules are small spherical particles which, by virtue of their internal energy, are bouncing around very rapidly In the gaseou

state the motion is very pronounced and the molecules display a wide range of velocities Molecules of a given substance display a characteristic average speed For nitrogen this is approximately 50 000 cm per second, or nearly one-third of a mile per second, under normal conditions of pressure and temperature The properties of gases vary noticeably with temperature and pressure

States of Matter. Matter ordinarily exists in three states gaseous, liquid, and solid From the viewpoint of the kinetic theory, the distinction between these states is based upon the proximity of the molecules and the corresponding restrictions placed upon their freedom to move about They enjoy the most freedom in the gaseous state, but in the solid state they are hemmed in so closely and are acted upon so strongly by intermolecular forces that they are forced to vibrate with very small amplitudes about their equilibrium positions The transitions from state to state are effected by rather complicated energy transformations Discussion is usually limited to the gaseous state in elementary courses in physics because this is fundamentally not only the simplest state but the one best understood at the present time Theory and experiment check very closely for this state For this reason the theory is often referred to as the kinetic theory of gases

Boyle's Law and the General Gas Law One notable success of this theory is its explanation of *Boyle's Law* This is the law discovered by Robert Boyle in 1662 or thereabouts, which states that a given mass of gas at constant temperature can undergo a decrease in volume only by a corresponding increase in pressure, and vice versa See fig 7 4 As a consequence, whatever the pressure or volume of gas the product of the pressure and the volume of a given amount is always the same An extension of this to include the effect of temperature is given by *Charles's Law*, and the combined effect of all three factors—pressure, volume, and temperature—is the *General Gas Law*, which states that the volume multiplied by the pressure

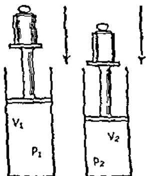


Fig 7 4 As the volume of a gas is decreased its pressure is increased and vice versa if the temperature and mass are left constant.

and divided by the absolute temperature is always constant for a given mass of gas Absolute temperature will be defined later Specifically this law means that if one factor is kept constant the variation in the other two is predictable At constant pressure the volume is increased directly as the temperature is raised At constant volume the pressure and temperature increase together At constant temperature, we have Boyle's law itself Although these results follow from experiment, it is a remarkable fact that they can be derived mathematically from the kinetic theory of gases

Avogadro's Law and Number. This theory also verifies the postulate put forward by the Italian chemist Avogadro (1776–1856) who followed Boyle (1627–1691), that under the same conditions of temperature and pressure there is always the same number of molecules in a given volume of gas The number of molecules in a cubic centimeter of gas at normal atmospheric pressure and at the temperature of melting ice (these conditions are referred to as normal conditions in scientific work) is enormous It is the number obtained by moving the decimal point in the number 2 7 nineteen places to the right This is comparable with the fact that the diameter of a molecule is only 2 or 3 hundred millionths of a centimeter If one can imagine small spheres packed in a cubical container one centimeter to the side (less than one-half an inch) with each sphere only a few hundred millionths of a centimeter in size, they would be far from crowded In fact, there would be ever so much more space between the spheres than that occupied by them The situation has been compared, for simplicity, to a gymnasium approximately 100 ft by 50 ft by 15 ft high containing only 50 basketballs Certainly the hall would not be said to be crowded with basketballs, even if they were all in the air at one time This is the approximate manner in which air molecules, for example, are packed into every cubic centimeter of air about us

Approximate Nature of the Gas Laws Upon close examination it is found that Boyle's law and the general gas law are only approximate laws Precise experimentation has shown that there are slight deviations from these laws in all observable cases Moreover, the deviations become more and more noticeable as we pass from simple gases like hydrogen and helium to gases of greater chemical complexity, and as we pass to extreme conditions of pressure and temperature

Concept of the Ideal Gas The scientist has found an ingenious way to cope with this situation Because all gases obey the gas laws approximately and because the deviation in no case is relatively very large, the concept of the ideal gas has been invented An *ideal gas* is defined as one which obeys these laws absolutely Real gases are treated according to their degree of deviation from the ideal gas law This seems to be a good way of handling the situation because of the complexity which would arise if each case were considered independently Moreover, the concept has been of inestimable value in organizing the known facts about gases in a general way Much of the research work today is concerned with the individual details, however, now that it is felt that the main portions of the picture are essentially correct

The Nature of Ideal Concepts in Science. This procedure exemplifies a characteristic of the modern scientist Starting with an oversimplified postulate, he continually corrects and revises it as the experimentation progresses, filling in the details as he proceeds In some cases, strangely enough, the details have not fitted in so smoothly as they were expected to, and often major discoveries regarding main points have thus been made This has been particularly characteristic of the so-called modern physics Whereas around 1890 it was thought that all major discoveries in physics had been made and there was nothing left except the job of filling in details by precision-type measurements, quite the opposite has actually been the case In repeated instances the polishing off, so to speak, has uncovered vast areas of unexplored territory, the developments of which not only have added materially to the store of knowledge, but also have changed entirely the whole point of view Indeed, we live in an age when people like Einstein, working with the most abstract types of mathematics, have evolved viewpoints of physics in many instances so different from the views held only two generations ago, that it is sometimes hard to believe that physics has not become pure philosophy Many of the concepts of modern physics are purely mathematical in nature and are not capable of translation into physical pictures Nevertheless, much of the old remains, and it is the belief of some that many of the newer ideas are incapable of being intelligently understood until the shortcomings of the older and more natural views are appreciated It

must never be forgotten, however, that the physics of the pra tical world, the world of machines and men, is much the sam today as ever

Gas Pressure on the Kinetic Theory. Going back to tl kinetic picture again, we readily see how the concept of pressu is explained Just as a continuous stream of machine-gun bulle will cause a target to act as if it were being subjected to a stead force (see fig 7 5), so does the continuous bombardment of tl walls of gaseous containers by bouncing molecules produce a pe

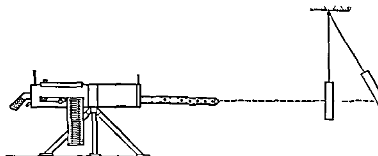


Fig 7.5 Continuous machine gun fire develops a steady pressure on a target

pendicularly directed force which, taken over a unit of are becomes a pressure in the same sense as the term was original defined Moreover, it is clear how this pressure should increa if the volume of a container should be reduced The molecu would be crowded more closely together so that the frequen and therefore the force of their collisions would be increas

Absolute Zero of Temperature Suggested by the Kine Theory. An additional postulate of the kinetic theory is tl the temperature of a gas is directly related to the molecular a tivity, whence it is also clear how the pressure increases wi temperature This suggests a lowest possible temperature in t world as that temperature for which molecular activity ceas It will be necessary to discuss this point more fully in a la chapter on heat, but suffice it to say here that this is the so-cal absolute zero of temperature It is 459 Fahrenheit degrees bel zero, or minus 273° Centigrade

Effects of Molecular Forces No discussion of molecu considerations would be complete without mention of some

re effects of molecular forces One of these is the phenomenon f surface tension Molecules display forces of attraction between hemselves Forces between like molecules are called *cohesive* orces and those between unlike molecules are called *adhesive* orces It is the former which hold bodies together and the latter which make different bodies stick to each other At the surface of a liquid these forces produce an effect suggesting the existence

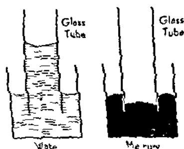


Fig 7 6 Water sticks to clean glass but mercury tends to pull away from glass



Fig 7.7 A steel needle can be floated on the surface of water

of a membrane stretched over the liquid so *as to make the sur*face of a given quantity of liquid always as small as possible The phenomenon is usually referred to as *surface tension* In certain instances the adhesion forces between *two substances* exceed the cohesion forces tending to hold the given substance together For example, water sticks very readily to a chemically *clean surface* of glass See fig 7 6 On the other hand a drop of *mercury placed* on a plate of clean glass tends to avoid the glass and *pulls itself* up into a hemispherical droplet Drops of water on a greasy glass surface do much the *same* thing

Capillary Attraction This same phenomenon also causes water *to rise up in small* capillary tubes (see fig 7 6) producing the many so-called capillary effects such as those which keep *ink from* running out of a fountain pen, keep the moisture in the *soil, etc* The opposite effect—i e, the repulsion of water from greasy surfaces—is utilized in water-proofing garments, tents etc It is because of this same effect that insects can walk on the *surface of liquids* It is also possible to float a steel needle on the surface of water in spite of the fact that steel is several times *denser than* water See fig 7 7 It is merely necessary that the

needle be coated with a very thin film of oil or grease such as it may always have unless specially cleansed by chemical methods The formation of drops of all kinds is also due to surface tension

Diffusion Other examples of molecular phenomena are diffusion and osmosis If two liquids are brought into contact with each other in a tube even if care is taken not to mix them together before long it will be found that one has penetrated into the other This is called *diffusion* Gases diffuse very readily as is evident by the fact that the presence of a volatile substance can be detected by its odor throughout a whole room very soon after it has been released in one corner of it

Osmosis Certain substances act like one way gates for certain fluids A sugar solution can penetrate in one direction only through the tissues of some fruits and vegetables Everyone is familiar with the fact that certain fruits when soaked in water take up the water even to the point where they swell up because of the pressure built up by the water The water does not come out but only goes into the fruit through its surrounding membrane This phenomenon is called *osmosis* The pressure developed is referred to as *osmotic pressure* Osmosis accounts for the rise of moisture up into high trees through their cellular walls to nourish them The growth of plant life is very dependent upon the existence of osmotic pressure

Summary Summarizing the material of this chapter we have seen that all matter is made up of small units such as molecules atoms electrons etc We have considered the highly successful kinetic theory of the structure of matter emphasizing those aspects which apply to the gaseous state Various other molecular phenomena have also been treated so that up to this point in our description of physics we have dealt with the mechanical elastic and material phases of the subject We proceed next to the study of heat and thermometry which we shall consider from the view point of energy

QUESTIONS

1 How many molecules are there in a cubic centimeter of a gas under normal conditions?
2 What is some of the evidence in favor of the molecular theory?

3 A bubble of air becomes larger as it rises in a container of water Explain
4 How does one explain the rapid permeation of an odor throughout a room?
5 For what is the physicist Bohr famous?
6 Distinguish between the electron and the proton
7 What is Boyle's law and what are its limitations?
8 Does a body whose density is appreciably greater than that of water necessarily sink in water?
9 Distinguish between capillarity and osmosis
10 Explain how rough water is made calmer by pouring oil on it

REVIEW QUESTIONS

(See page 190 for answers)

Chapters V, VI, and VII

1 Elasticity is a property of matter by virtue of which 1 liquids are distinguishable from gases, 2 Archimedes' principle holds, 3 bodies recover from deformations, 4 open pipes have more over tones than closed ones, 5 pressure is dependent upon density ( )
2 Simple harmonic motion is characterized by the fact that 1 the motion is periodic, 2 the acceleration is proportional to the displacement from the [illegible] 3 [illegible] 4 the [illegible] ( )
3 [illegible] displacement 2 the maximum displacement from the zero position 3 synonymous with the frequency of vibration 4 the number of vibrations per second, 5 twice the maximum displacement ( )
4 Within the elastic limit 1 stress is always zero [illegible] ( )
5 [illegible] closely with elastic phenomena 1 Hooke 2 Boyle, 3 Archimedes 4 Newton 5 Helmholtz ( )
6 Ivory soap floats in water because 1 all matter has mass 2 all matter has density 3 the density of [illegible] ory of [illegible] ( )

7 When a body is partially or wholly immersed in a liquid 1 it always sinks, 2 it is buoyed up by a force equal to its own weight, 3 it is buoyed up by a force equal to the weight of the liquid displaced, 4 it is buoyed up because of Archimedes' principle and always floats, 5 it is buoyed up by a force equal to the weight of water which it would displace ( )

8 If the mass of a body vibrating at the end of a vertical spring should be increased 1 the frequency of the vibrations would be increased, 2 the period of the vibrations would be increased 3 the amplitude would be decreased (4) the displacement of the body would be decreased, 5 the resonance frequency would be unaltered ( )

9 Chladni figures are 1 wave patterns produced on a vibrating stretched cord 2 always longitudinal vibrations, 3 always present in sound waves 4 patterns produced in vibrating plates, 5 the same as antinodes ( )

10 When a wave travels from one medium to another of different elastic properties 1 the wave length is unaltered 2 the frequency is changed 3 the velocity is changed 4 beats are established, 5 sounds are produced ( )

11 Kundt's apparatus was demonstrated in the lecture to show 1 vibrations in plates, 2 vibrations on cords, 3 beats, 4 overtones 5 standing waves in air columns ( )

12 Sound is a wave phenomenon of the following type 1 longitudinal 2 transverse, 3 torsional, 4 circular, 5 elliptical ( )

13 Standing waves are always 1 transverse, 2 longitudinal, 3 torsional 4 the result of interference, 5 the result of refraction ( )

14 Kundt's apparatus is used to measure 1 the velocity of sound, 2 the velocity of any wave motion, 3 the elasticity of a vibrating medium 4 the number of overtones in a rod, 5 a harmonic series ( )

15 Wave length of a wave is 1 the same as the frequency 2 the velocity of the wave divided by the frequency, 3 the product of velocity and frequency, 4 always zero in air, 5 the distance from a crest to the next trough ( )

16 [illegible]

sults 2 constructive interference always results, 3 refraction is demonstrated, 4 the phase difference is always zero, 5 standing waves are produced ( )

17 In air columns with one end open and the other end closed the wave length of the fundamental mode of vibration is 1 four times the length of the column 2 twice the length of the column 3 always zero 4 indeterminate, 5 the distance between two nodes ( )

18 A node is a point in a wave pattern where the disturbance is 1 a maximum, 2 a minimum 3 a rarefaction, 4 a condensation 5 always varying ( )

19 Sound waves 1 do not travel in a vacuum 2 travel best in a vacuum, 3 travel with a velocity of 186 000 miles per second 4 are transverse waves, 5 are always capable of being heard ( )

20 Pitch is 1 the number of vibrations per second, [illegible] ( )

21 [illegible]

ence of overtones 4 the pitch 5 the frequency of the [illegible] ( )

22 The nu [illegible] forks [illegible] fork 2 is independent of the frequency of either fork 3 is exactly equal to the difference in frequency between them 4 is approximately equal to the difference in frequency between them 5 is always audible ( )

23 Atoms are 1 indivisible 2 invisible 3 truly spherical 4 always stationary 5 composed of molecules ( )

24 A long glass tube of mercury with its open end immersed in a dish of mercury can be used to demonstrate the fact that 1 molecules are small 2 the atmosphere is made up of nitrogen and oxygen 3 the atmosphere exerts a pressure 4 Boyle s law is true 5 pressure is the result of molecular bombardment ( )

25 In order to compress a gas to one half its initial volume at constant temperature the pressure

Nature of Heat—Early View vs. Rumford's Interpretatio By the ancients, heat was thought of as a fluid of some kind the addition of which to a body made it hotter, and the subtrac tion of which from a body made it colder This so-called calorific fluid was a concept which seemed to explain many of the ob servable thermal phenomena, but it had one serious drawback All attempts to determine the density of the supposedly material substance failed About 1800 the American-born Benjamin Thom son, later Count Rumford, offered a new interpretation Engaged in the manufacture of cannon, in which one operation was boring Rumford observed that although chips were removed there was a noticeable rise in temperature This was not consistent wit the calorific fluid theory because the removal of chips should, on the theory, be accompanied by a loss of heat along with the chips removed Furthermore, he observed that there was more heat generated with a dull tool than with a sharp one, although the latter removed more chips He sensed the fact that the amount of heat generated was directly related to the amount of energy expended rather than to the number of chips or the amount of material removed Of course one must work harder with a dull drill than with a sharp one to bore out the same amount of mate rial

Heat a Form of Energy Thus was conceived the idea that heat is really nothing more nor less than energy itself Later ex periments by the Englishman Joule and the American Rowland disclosed the direct equivalence of these two This view is al o consistent with the modern kinetic theory of matter, already dis cussed, in terms of which heat is found to be just that energy *associated with the random motion of molecules* On this basis friction develops heat simply because of, and in an amount equal to, the increase in the molecular energy associated with th haphazard, random molecular motion involved when two su stances are rubbed together Indeed, on the kinetic theory, heat is defined simply as the total energy associated with this random haphazard molecular motion Moreover, temperature, althou h qualitatively definable as a property which determines the direc tion in which heat will flow (it always flows of its own accord from high-temperature regions toward lower-temperature re gions), fits into the kinetic picture as the average kinetic energy per molecule associated with the translatory motion

Thermometry. Before we can pursue farther this matter heat and temperature it is necessary that we understand how mperature is measured. This phase of the subject is called

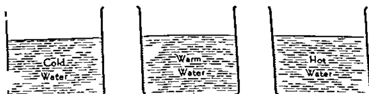


Fig 8.1 The warm water feels hot to the hand previously placed in 'd water but cold to the hand previously placed in hot water, showing temperature is a relative matter

iermometry Of course, we might rely upon our sense of warmth ! cold, but it can be readily shown that such determinations very unreliable If one were to place a hand in warm water fter it had been in hot water the warm water would feel cold, hereas the same hand in warm water would seem hot after hav- g been placed in cold water See fig 8 1 This shows how rela- the matter of temperature is In order to make a more re- determination of temperature we look to the various -operties of matter which are found to be tered by the application of heat and note that all matter usually expands when

Thermal Expansion Utilized in Tem- Measurements Liquids, generally eaking, expand more noticeably than solids, l gases expand still more The liquid sub- ance mercury expands very uniformly over considerable range of temperature and so 'es us with a suitable thermometric sub- ance which, in the form of a fine thread in glass capillary tube, sealed to an expansion , constitutes a useful thermometer See 8 2



Fig 8.2 Mercury in glass thermometer

All temperature readings are relative The graduations on a iermometer scale are made to agree with conventional stand- on the basis of which certain temperatures are accepted as ..ed points The two most conspicuous fixed points are the tem-

perature of melting ice and the temperature at which water boils under normal atmospheric pressure, i e, 76 cm of mercury or 14 7 lbs per sq in It is merely a matter of common agreement that these are the temperatures which are basic to all thermometric work

Centigrade vs Fahrenheit Temperature Scales We have two relatively common scales of temperature the Centigrade scale, used chiefly in scientific work and the Fahrenheit scale, which is perhaps more familiar to the layman. On the Centigrade scale the melting point of ice, which is the same as the freezing point of water is arbitrarily called 0° C, and the boiling point is arbitrarily called 100° C On the Fahrenheit scale, these are called 32° F, and 212° F, respectively See fig 8 3 It is further noted that the Centigrade scale is subdivided into 100 equal degrees between freezing and boiling temperatures, whereas the Fahrenheit scale is subdivided into *180* equal degrees over the same region, each Fahrenheit degree being 5/9 as large as a Centigrade degree

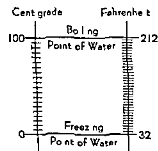


Fig 8.3 The Centigrade and Fahrenheit temperature scales compared

Converting from One Scale to the Other It is obviously a simple matter to change a temperature reading on one scale to the corresponding reading on the other one since the Centigrade degree is 9/5 as large as the Fahrenheit degree and the freezing point of water on the Fahrenheit scale is already 32 degrees above zero Thus the familiar temperature 68° F is 36 Fahrenheit degrees above the freezing point, and so corresponds to only 20 Centigrade degrees above the freezing point, or to just 20° C Incidentally the temperature reading of 40° below zero happens to be the same on each scale

Coefficient of Thermal Expansion Whereas different solids and liquids expand quite differently, all gases expand by approximately the same amount The fractional expansion of any portion of a substance per degree of temperature change is defined as the *coefficient of thermal expansion* of the substance Expansion in one dimension only, i e, of length, is called linear expansion We may also consider surface and volume expansion The *coefficient*

f volume expansion for a substance is necessarily approximately hree times the size of the linear coefficient

Expansion of Gases. The volume coefficient is approximately *he same for all gases and* is very nearly equal to the reciprocal of the number 273 per degree Centigrade This means that, as he temperature of a gas at 0° C is raised one degree, its volume increases by 1/273rd of its original value. *This also* means that a gas *shrinks in volume 1/273rd of its* value if it is cooled one degree Centigrade, and this brings up the interesting question of what would happen to a quantity of gas if its temperature should be reduced by 273 degrees from 0° C

Concept of Absolute Zero of Temperature. The answer to this question, i e, whether or not the volume vanishes completely, cannot be found experimentally because of the impossibility of lowering the temperature of any gas to − 273° C All known gases liquefy before this temperature is reached, and liquids do not have the same coefficients as gases There is, however, something unique about this temperature of − 273° C As has been

this is significant, for the kinetic theory also requires the pressure of a gas to vanish when the temperature is reduced to absolute zero Thus, and for more technical reasons not to be considered here, an absolute zero of temperature has been postulated, a temperature so low that, on the kinetic theory, all molecular motion ceases This temperature therefore is − 273° C, or about − 459° F, and its existence implies the absolute inability of any lower temperature to exist This is the first place in our study *where a limitation has been imposed upon our thinking of extremes* of anything such as size or intensity, but it will not be the last one

Absolute Temperature Scale. Thus a *third, or absolute,* scale of temperature is suggested, based upon this absolute zero

Absolute. In engineering work, however, an absolute Fahrenheit scale is som

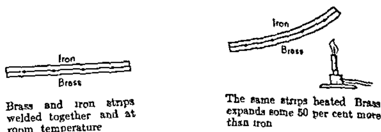
Further Significance of Absolute Zero In recent ye techniques have been developed by experimenters for produc very low temperatures to learn about these extreme conditic Although no one has succeeded in producing a temperature lo than absolute zero, and of course, present-day science pred: that no one ever will, nevertheless values within a very sm fraction of a degree of absolute zero have been obtained In *dentally, it should be noted that the measurement of such te* perature is by no means a simple matter The field of lo temperature research appears to hold great promise for st tling discoveries in the near future Many of the properties matter have already been found to vary markedly from tl normal values when samples are subjected to very low tempe tures

Molecular Forces Involved in Thermal Expansion Gc back to the question of linear expansion of solids, attentio called specifically to the magnitude of the molecular forces volved when a rod, say of steel, is heated Steel increases length by approximately eleven parts in a million, per deg Centigrade This means that a steel bridge one mile long, example, changes in length by more than four feet unde change in temperature from a winter's minimum of 40° bel zero to a summer's maximum of around + 100° F When considers how much force is required to stretch a steel rod eleven parts in a million one can only marvel at the quiet m ner in which a rise of temperature of only one degree Centigr produces the same effect

Bimetallic Expansion—Thermostats If a strip of iro securely fastened along its length to a strip of brass of the sa length, and the combination is then heated, the result will b bending of the combination, because brass expands nearly 50 cent more than iron See fig 8 4 This effect is utilized in various bimetallic thermostats which are so common in numerous automatic control devices In all these devices elec contacts are simply made and broken by such a bending of metallic strips upon the application of heat

Attention is called, incidentally, to the very fortunate that cement and steel have practically the same coefficient expansion This makes possible the modern steel and cem

skyscraper, which does not buckle with changes in temperature In fact, reinforced concrete in general, which plays such an important part in our highly mechanized lives, is possible only because of this fact



Brass and iron strips welded together and at room temperature

The same strips heated Brass expands some 50 per cent more than iron

Fig 8 4

The General Gas Law Since the volume of a gas varies with temperature, as indicated above, and since Boyle's law, previously discussed, states how the volume of a given mass of gas depends upon the pressure, it is natural to wonder if these two effects can be combined into a general law This actually proves to be the case, and for the ideal gas, the relation is a very simple one It is usually referred to as the *general gas law* It states that the pressure multiplied by the volume and divided by the absolute temperature of a given mass of gas is constant This simply means that if the volume of a given mass of gas is kept constant, its pressure varies directly as the absolute temperature Of course, if the temperature is kept constant this is simply Boyle's law itself, i e , the pressure is inversely proportional to the volume Temperatures, in this connection, must always be expressed on the absolute scale

Concept of Temperature Only Part of the Study Thus we see that one of the outstanding characteristics of matter, namely size, is affected by the application of heat, and that variations in the size of an object may be utilized in the measurement of temperature Of course, this is consistent with the kinetic theory of matter, since an increase in the size of a body can be thought to be associated with an increased molecular activity, which requires more space For a further insight into the nature of heat we shall be required to consider the question of the quantitative measurement of heat

ing temperature is raised, as in the case of the pressure cooker See fig 8 5 At high elevations, on the other hand, where the pressure is low, the boiling temperature is also low In fact it may be too low for certain foods to be cooked by boiling, as is well known by passengers on air liners Whereas chemistry teaches that substances can be identified by characteristic boiling points, it must be pointed out that it is necessary to establish some standard of pressure such as standard atmospheric pressure, 76 cm of mercury or 14 7 lbs per square inch, in this identification process

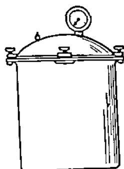


Fig 8.5 With the pressure cooker the boiling point of water is raised above 100° C or 212° F

Boiling under reduced pressure can also be illustrated by the so-called Franklin pulse glass This is a dumbbell-shaped glass tube, i e , a slender tube with spherical bulbs at either end, partially filled with colored water and sealed off under reduced pressure Just the heat of the hand clasped about one bulb causes sufficient rise in temperature to make the water boil over into the other (cooler) bulb

Boiling vs Evaporation—Vapor Pressure In connection with the discussion of boiling it might be well to distinguish between the phenomenon of boiling and that of evaporation It is well known that water left in an uncovered dish will eventually disappear by evaporation This is the result of molecular activity at the surface, and is quite understandable from the kinetic theory The molecules simply bounce away In the case of boiling, however, the change of state more frequently than not takes place down inside the water, even at the very bottom, where heat is perhaps being applied by a flame If, however, a cover is placed over the evaporation dish in which there is some water, the molecules are confined above the surface of the liquid, and build up a pressure as they accumulate At a given temperature, there is a certain maximum value which this pressure can reach for any particular liquid This is known as the *saturated vapor pressure* From this point of view the boiling point of a liquid is simply that temperature at which the saturated vapor pressure coincides with the atmospheric pressure

Humidity The effects of water vapor in the air afford an

interesting study Everyone knows that atmospheric moisture is a very important factor in connection with the weather There is obviously a limit to the amount of moisture which the air can hold at a given temperature If the maximum is reached, precipitation results This condition is referred to technically as a condition of 100 per cent relative humidity, where the term *relative humidity* is the ratio of the amount of water vapor in a given volume of air to the maximum amount possible at the temperature in question The actual amount of water vapor present in a given volume of air is called *absolute humidity* The measurement of humidity is called *hygrometry* It can be accomplished by the use of the sling hygrometer See fig 86 Whirling the device keeps the air circulating and enhances the evaporation of moisture from the wet bulb Because evaporation causes cooling there is a difference in temperature readings of the two thermometers which is thus related to relative humidity

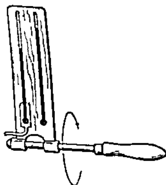


Fig 86 Relative humidity can be measured by the sling hygrometer in which a wet-bulb and a dry bulb thermometer are rotated in a frame about an axle The amount by which the dry bulb reading exceeds the wet-bulb reading is a measure of the relative humidity

Dew Since the limit to the amount of moisture possible in the air varies with the temperature—actually it increases with temperature—we have the phenomenon of the *dew point* An amount of water vapor which is not sufficient to produce saturation at one te — do so howe er

temperature

moisture, or ,

because the temperature of the pitcher is sufficiently lower than that of the surrounding air for the amount of water vapor present to produce saturation Similarly dew is formed on the grass on

h temperat re s low er d gr

freezes and becomes frost

ing temperature is raised, as in the case of the pressure cooker See fig 8 5 At high elevations, on the other hand, where the pressure is low, the boiling temperature is also low In fact it may be too low for certain foods to be cooked by boiling, as is well known by *passengers on air liners* Whereas chemistry teaches that substances can be identified by characteristic boiling points, it must be pointed out that it is necessary to establish some standard of pressure such as standard atmospheric pressure, 76 cm of mercury or 14 7 lbs per square inch, in this identification process

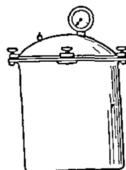


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Humidity The effects of water vapor in the air afford an

be distinguished from gases, but today no such distinctions are attempted because it is known that all gases can now be liquefied and even solidified Liquid air, for example, is a very familiar substance in the scientific laboratory It of course, boils freely at room temperature and atmospheric pressure although its tem perature is 180° below zero Centigrade One has to be careful not to confine liquid air in a stoppered container because at room temperature its saturated vapor pressure is many, many atmospheres For the same reason it is not safe to confine dry ice in a stoppered container at room temperature The vapor pressure which it will build up is enormous

Effect of Pressure upon the Freezing Point Thus it is seen that the state in which matter exists depends among other things upon its thermal condition At the boiling point the liquid and gaseous states exist in equilibrium with each other, and at the freezing point the liquid and solid states are in equilibrium Although the boiling temperature of water is appreciably altered by a moderate change in pres sure the freezing point is only slightly changed Enormous pres sures however, can reduce the melting point appreciably Ice skating is in reality a process of slipping along on a thin film of water immediately beneath the skate's runner a condition pro duced by local melting of the ice under the pressure exerted by the weight of the skater acting upon the relatively small area of sur face supporting the skate Upon the removal of the pressure, after the skater slips along this thin film of water freezes almost instantly *Regelation* is the technical name for this phenomenon of melting under pressure and refreezing upon its removal See fig 87 It suggests the man ner in which the glaciers probably slipped along over large sec tions of the earth at an earlier period

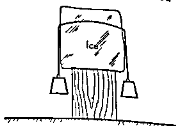


Fig 87 Regelation illustrated by a wire which gradually cuts" through a p ece of ice owing to weights fastened at its ends The ice fuses together after the wire passes through successive portions

Summary In this chapter we have seen how heat is simply a manifestation of energy, how it is distinguished from temp ture and how the latter is measured by virtue of certain th

properties of matter, particularly expansion. We have also considered briefly how heat is measured and how thermal considerations enter into questions involving states of matter, and change of state We shall turn next to a descriptive consideration of heat transfer and allied phenomena

QUESTIONS

1. Why does the mercury thread in a glass thermometer usually fall a little when the thermometer is first placed in hot water?
2. A pyrex dish is less likely to break when heated than an ordinary glass dish. What can be said of the relative expansion coefficients of these two substances?
3. Is there any sense to the procedure of dipping a metal can cover in hot water to make it come off more easily?
4. What is the distinction between heat and temperature?
5. List various effects produced by a temperature change which may be utilized to measure temperature
6. A Centigrade thermometer reads $-40°$ What would be the reading on a Fahrenheit thermometer?
7. It is often possible by gentle heating to remove the stopper from a glass bottle after it has become stuck Explain
8. Is a gallon of boiling water any hotter than a pint of it? Does the one contain more or less heat than the other?
9. Why does steam at 212° F cause a more severe burn than boiling water at 212° F ?
10. Why does a gas become heated on compression and cooled on expansion?
11. Explain why the air escaping from an automobile tire valve feels cold
12. Explain why it is impossible to skate on glass
13. The substance hypo is often used instead of ice on indoor skating rinks What characteristics does it have to make it suitable for this purpose?
14. Why does it become necessary to add moisture to the air of a house in the wintertime?
15. Explain why moisture collects on the outside of the ice-water pitcher
16. Explain why perspiration is more bothersome on a humid day than on a day less humid even if the temperature is the same

CHAPTER IX

THERMAL CONSIDERATIONS (*Continued*)

THE NATURE OF HEAT TRANSFER QUANTUM THEORY, AND CERTAIN OTHER PHILOSOPHICAL CONSIDERATIONS

Heat Is Transferable from Place to Place. In the [illegible] chapter it was noted that temperature could be thought of as a property which determines the direction of heat flow from one body to another body in contact with it That heat does flow from one region to another is not an unfamiliar fact, and so a study of the manner in which it flows becomes an important part of the course in general physics

Heat (Not Cold) Flows In the first place, it [illegible]

gions it must be forced—i e work has to be done [illegible] more, this means that "cold" does not move Cold [illegible] of heat It is only the latter, the energy associated [illegible] dom motion of molecules, that flows Thus it is not [illegible]

insulation is nothing more nor less than the [illegible] flow and is therefore a part of the larger [illegible] which we shall now consider

Three Modes of Heat Transfer (Cond[illegible] Radiation) There are three recognizable [illegible]
may [illegible]
call [illegible]

Conduction When an iron poker is held with one end in a fire, heat is observed to travel from the hot end to the cold end passing successively from point to point throughout the length of the poker This is the type of transfer called *conduction* In terms of the kinetic theory the molecular agitation is simply passed along from molecule to molecule in much the same manner as a

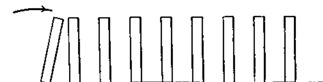


Fig 9 1 If the end domino in a row is pushed over kinetic energy will be passed on from domino to domino This is analogous to the process of heat conduction

column of closely spaced, standing dominoes is toppled over if the first one in line is pushed backward Each domino in succession is pushed over See fig 9 1

CONDUCTIVITY Different substances have different *coefficients of conductivity*, determined by the rate at which heat is conducted through unit length of the substance when a unit difference in temperature is maintained between the ends of the sample of unit cross sectional area The best known conductor of heat is silver, which, incidentally, is also the best known conductor of electricity Insulators are simply poor conductors Whereas the metals are good thermal conductors, substances like cork and wool are good insulators Air also is a poor conductor, i e, a good insulator, and much of the merit of a fur lined coat lies in the poor conductivity of the air spaces between the hairs of the fur There is the same reason for double walled construction of houses in which an air space is left between the walls Because powdered asbestos is also an exceptionally good insulator, i e, a poor conductor, it is commonly blown into the space between the walls of old houses these days to improve the insulation It should be noted, of course that if heat could be prevented completely from escaping through the walls, windows roofs etc of houses they could be heated at practically no expense at all This is why so much attention is given to the question of insulation in ' the house of the future '

The advent of the electric refrigerator has focused considerable attention upon the matter of heat insulation For reasons of

operating economy the builders of electric refrigerators were forced to develop boxes insulated to such a degree of refinement that the manufacturers of iceboxes are now able to offer boxes that need to be filled with ice only once a week It is entirely a

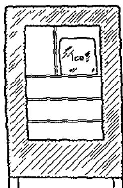


Fig 9.2 Insulation is the secret of the successful icebox Heat is prevented from flowing in from the outside to melt the ice Only heat from the food inside the box is allowed to melt the ice

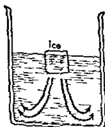


Fig 9.3 Convection currents are set up by an ice cube floating in a glass of water Cold water sinks and gives way to warm water which rises

matter of preventing the flow of heat from the outside to the inside of the box that accomplishes this result See fig 9.2

Convection The second mode of heat transfer, which we shall now consider, is *convection* This is characterized by the word circulation ' If an ice cube is placed in a glass of water it is found that currents are established in the water See fig 9.3 The coolest water sinks to the bottom of the glass and the warmer portions rise to the top This is due to the difference in density between warm and cold water and the natural application of Archimedes principle, already described Such currents are known as *convection currents,* and the phenomenon of heat transfer by such means is called *convection* It is characterized specifically by the acquisition of heat by some material agent which moves

mea ure by con e

registers It is to be noted that those houses which heat best are

those in which a good circulation of air is provided by the arrangement of the rooms The old-fashioned long, narrow house with rooms following one after another is hard to heat uniformly This is not the case with houses in which the rooms are clustered

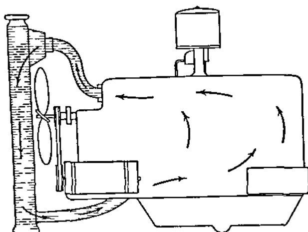


Fig 94 Cooling is accomplished in the radiators of certain cars by convection currents Hot water in the engine rises and is allowed to fall through tubes in the radiator thus becoming cooler and displacing warmer water at the bottom

around some central point with open doorways providing free access from one to another, including the last and the first

The principle of heat transfer by convection is still utilized in the cooling systems of some automobiles, although most of the cars today have water pumps for this purpose The hot water in the engines of these cars rises to the top of the radiator where it falls through narrow tubes of brass from which, by conduction much of the heat is removed to the out of doors At the bottom of the radiator the water becomes cool, forcing more hot water up through the motor to the top of the system, where the process is repeated This is the so called thermosyphon system See fig 94

METEOROLOGICAL ASPECTS OF CONVECTION Convection currents of air play a very important role in the production of weather Heated air masses rising rapidly by convection on a hot day are the cause of most thundershowers The electrical phenomena involved in such showers will be discussed in a later

chapter, but the cloud formations responsible for them are pro-

currents, have advanced the study of meteorology in the last decade or so to an unprecedented degree

Radiation The last of the three modes of heat transfer to be considered here is radiation It is a known fact that a person's hand placed a few inches beneath a hot household radiator feels warmth from the radiator See fig 9 5 Similarly, warmth is felt a few inches from the floor in front of a glowing fireplace fire In neither of these cases is the transfer of heat due chiefly to conduction or convection In the first place air is a very poor conductor, and in the second place convection carries heat upward and not downward In these cases the heat is *radiated* directly outward i e, it is transferred much as light is transferred by some kind of wavelike process This process of heat transfer has been studied at great length by physicists throughout the ages, because it has been one of the most difficult and most confusing of all the questions raised by natural philosophy It is the question of the nature of radiant energy and embraces not only the nature of heat radiation but also that of light, radio X rays, cosmic radiation, and many allied phenomena, although much of this material will have to wait for later consideration

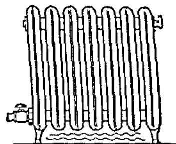


Fig 9.5 Heating underneath a radiator is accomplished largely by radiation

Nature of Radiant Energy A great deal of attention has been given to the question of whether this radiation is corpuscular or wavelike, and although the present view is very complicated by virtue of certain nonmaterialistic concepts associated with such subjects as quantum theory and relativity, the view has been developed that for the most part radiation is wavelike Heat radiation then, is the same as light radiation except that the length of the waves containing the bulk of the energy is different in each case Generally speaking, heat waves are

than light waves, but the speed at which they travel in empty space is the same In fact, both kinds are liberated simultaneously and at the same speed, by a common source because they really are both part of the same thing Actually it is more accurate to say that a source of radiant energy radiates a whole spectrum of radiation, displaying wave properties and characterized by the lengths of the waves contained therein A certain portion of this spectrum is recognized as heat, and other portions as light, X rays, etc Whereas the range of visible wave lengths is recognized by

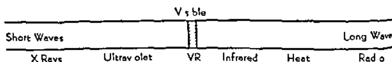


Fig 9.6 The electromagnetic spectrum extends all the way from the shortest X rays to the longest radio waves The visible portion comprises very narrow band from violet to red

the concept of color, extending from violet to red with wave lengths from 0 00004 cm to approximately 0 00008 cm respectively, heat waves extend from the infrared region out to the radio range where the lengths of the waves are measured in millimeters, centimeters, and even meters Beyond the violet side of the visible spectrum the waves range from the so-called ultraviolet, responsible in large measure for sunburn and tan, to the X rays See fig 9 6

Color Associated with Radiation. That color is somewhat with heat radiation may also be shown by calling attention to the familiar kitchen stove As a stove heats up, first notices the feeling of warmth before there is any indic of color, but at a certain temperature, the stove covers glow a dull red color This color changes with temperature, becoming more yellow and perhaps finally white hot as the perature increases, at which time it is found that a very wi range of wave lengths is being emitted Camera film sensi particularly for infrared is capable of detecting these radiations long before the stove becomes hot enough to glow visibly, and even in the dark Similarly it is possible to detect the various other wave lengths present in the radiations from the white hot covers The analysis of all these radiations is usually referred to as *spectroscopy* and will be considered more fully in the study of

light, where it seems to fit more appropriately into the scheme of physics The study of heat is so closely tied in with the study of light, and even of radio, as to make the study of any one topic alone nearly impossible

Law of Heat Radiation. Getting back to the study of heat radiation, we find there are certain laws governing this phenomenon The rate of radiation depends upon the size of the radiating surface, its absolute temperature, and its nature The dependence on temperature is not a straight proportionality but a fourth power proportionality, i e, a doubling of temperature, expressed on the absolute scale, does not double the rate of radiation, but increases it sixteenfold Thus, although all bodies with temperature above absolute zero radiate, hot bodies cool ever so much faster by radiation than cold ones

Surface Characteristics of Radiators. The nature of the radiating surface is very important as regards the rate of radiation Rough surfaces cool faster than smooth ones and black surfaces radiate faster than white ones The worst conceivable radiator, then, is a perfectly reflecting surface such as a highly polished silver mirror, and it is for this reason that modern flatirons are nickel plated all over except on the bottom, which is the only surface from which heat is allowed to escape This reasoning suggests certain facts well known to the practical person, such as that black stoves and radiators give off more heat than those painted in light colors, and that polished copper hot-water tanks retain heat longer than painted ones It is not just imagination either, that makes light-colored clothes feel cooler in the hot weather than dark ones Dark clothes actually are hotter because of radiation and its associated phenomenon of absorption A substance has to absorb heat in order to radiate it, and so a good radiator is a good absorber On the other hand, a woolen shirt is more comfortable than a cotton one if the wearer is exposed to the direct rays of the sun, even in the summer This is because of the poorer conductivity of the wool, rather than its radiation

[illegible]

tion with conduction may actually [illegible] is achieved three The success of the thermos bottle, for example, is achieved

by reducing all three modes of heat transfer to a minimum The thermos bottle consists of a double-walled container, whose wall are separated by a vacuum, the very worst heat conductor imaginable See fig 9 7 The only place wher heat can escape by conduction is through th stopper and this is usually small and mad of cork The vacuum space also eliminates th possibility of convection currents Finally the walls are usually silvered so that what ever heat might escape across the vacuum b radiation is reflected back into the bottl For these reasons, then, a good thermos bot tle can keep foods or liquids hot for a con siderable length of time The heat just cannc escape Moreover, a thermos bottle will kee cold things cold longer than it will keep hc things hot, because hot objects radiate moi rapidly than cold ones

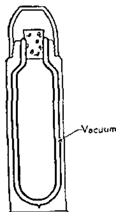


Fig 9 7 The thermos bottle is a double walled glass bottle The region between the walls is highly exhausted to prevent the transfer of heat by conduction and convection The walls are silvered to prevent radiation

Selective Transmission and Absorptio of Radiation That radiant heat has muc the same if not exactly the same nature a light is also shown by the fact that it can l reflected by mirrors and focused by lense Of course, certain substances are more tran parent to light waves (short) than to he waves (long) i e, they transmit waves one length but are opaque to waves of different length Son substances also absorb selected wave lengths The hothouse pro vides an interesting situation Light is readily transmitted throug the glass windows and much radiant energy is absorbed by tl objects and ground within the hothouse Upon absorption the bodies immediately reradiate the energy as heat waves but wi lengths too great to penetrate window glass See fig 9 8 Th energy enters via short waves but cannot escape because the sho waves are changed to long ones This emphasis on waves and the lengths naturally raises the question however as to the certaint of the view that radiant heat and light are wavelike Furthermor it must be admitted that no discussion of radiation would b complete without some reference to the now popular quantur theory, which contradicts the wave theory

The Quantum Theory. It was in about 1900 that Max Planck, the German physicist, was making an intensive study of the distribution of energy in the radiation spectrum. In an attempt to formulate a mathematical relationship governing the amount of energy allocated to the different wave lengths, i.e., associated with different colors, he became convinced that the laws of classical physics were inadequate to explain observable facts. In other words, his search for the truth, which is the ulti-

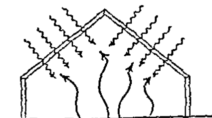


Fig. 98. In the hothouse short waves enter and are absorbed. They are transformed into long waves which cannot be transmitted by the glass.

mate task of the scientist, led to the conclusion that supposedly correct laws were not altogether true, and that all natural phenomena are not necessarily explainable in terms of simple postulates. In particular, he found that instead of assuming radiant energy to be propagated like a continuous wave disturbance, it is necessary to postulate that energy is radiated in packets or bundles each made up of an integral number of elementary units which [illegible] quanta. This seemed to many to be a very artifi-

the history of physics, this quantum [illegible] accepted view.

Some Philosophical Aspects of Quantum Theory. Even though this seems to give a corpuscular aspect to the nature of radiant energy, it has not eliminated the wave hypothesis, because of other phenomena (to be discussed later in optics, pp. 182–184) which cannot be explained by corpuscles unless the corpuscles themselves be thought of as bundles of waves. Thus radiation is still discussed in terms of waves, but also in terms of quanta, at the same time. If now this appears slightly indefinite to the stu-

dent, then he has just begun to grasp the point of view of the physicist of the last generation, who felt that the discovery of the quantum theory completely undermined all semblance of reality in physics During the last two or three decades, however, many of the philosophical aspects of this whole question have been straightened out in such a way as to show that the earlier views, although approximations to the truth, are not such good approximations as the later views It is as if the early views explained only main features but not details, whereas the present views are more comprehensive and correspondingly more complex

The "Newer" Physics Goes beyond "Classical Physics" Here it is that we begin to see how a change has come over physics since the turn of the century, and why it is that physicists refer to the New Physics as distinguished from Classical Physics The New Physics is permeated by a point of view altogether lacking in its respect for "common sense," but characterized by strictly mathematical logic and deductions from formal assumptions justified only by their observable results Although this is not the physics of Newton, it is nevertheless fair to point out that the major discrepancies between the two lie chiefly in the domain of submicroscopic affairs, and that most of the deductions from Newtonian physics still hold as true as ever in the ordinary mechanical world of men and machines

Additional Discrepancies of "Classical Physics" If the quantum theory were the only source of worry to the classical physicist we should probably not be so concerned about it, but the facts are that many of the supposedly minor discrepancies of classical physics have become grossly magnified by the researches of modern times, and, strangely enough, those measures required to restore order and reason to the troubled picture are extraordinarily consistent with the newer point of view exemplified by the quantum theory Specifically, we refer to the study of relative motion, which Einstein has explained only by reference to concepts and mathematical logic which do not seem sensible from the earlier point of view One of these, for example, is the relativity postulate that no body can have a velocity greater than that of light In brief, the modern physicists, attempting to understand nature, have discovered that instead of being faced with the task of polishing off certain rough spots of otherwise completely solved problems, they have hardly scratched the surface of much larger

and profoundly more significant problems There is, however, no reason to be discouraged, because the discoveries of the past have been very well consolidated and what lies ahead is merely a new era Much of the new physics deals with electrical phenomena, the elementary concepts of which we shall consider in the next chapter

Summary In this chapter the three modes of heat transfer—conduction, convection, and radiation—have been described Insulation is seen to be the inverse of conduction Conduction refers to the transfer of molecular energy right through an object Convection involves the circulation of heat by some agent which actually carries it from one place to another Radiation is a wavelike propagation quite different from the other two modes It is electromagnetic in nature like light, radio, and X rays It is best explained by the quantum theory, which has almost completely revolutionized the point of view of physics, so that modern physics is something more than an extension of classical physics, although the latter is a first approximation of the former

QUESTIONS

1 Some people boast of the length of time they can keep ice in a refrigerator by completely wrapping it in newspaper Comment
2 Why is a thick layer of air used for insulating ovens?
3 Icicles are sometimes observed to melt on the south side of a house before they do on the north side Why?
4 What is the effect of a fireplace on the ventilation of a room?
5 Why may a fireplace which smokes at first, stop smoking after a fire has burned a short while?
6 Explain how it is that a person in front of a fireplace fire may have a cold back yet feel hot in the face
7 Why does a thermos bottle keep cold things cold longer than it can keep hot things hot?
8 What are some of the features of the quantum theory?

CHAPTER X

ELECTRICAL CONSIDERATIONS

STATIC ELECTRICITY, CHARGES POTENTIAL, CAPACITY

In an earlier chapter reference was made to the electrical structure of matter It was pointed out that all matter is constructed fundamentally from charges of electricity The concept of electrical charge, although a somewhat abstract concept, is so important that it cannot go unmentioned in this description of the physical world In the beginning, the concept was just a device invented to describe a situation but later it was given reality by the discovery of natural units of charge Today it is felt that such units of charge as the electron, the positron, the proton, the mesotron, etc really exist and are fundamental entities basic to the very concept of matter itself Hence they invite our study

Frictional Electricity Proceeding historically and logically to the development of electrical knowledge, we start with a consideration of frictional electricity and electrostatics As was pointed out earlier, if a rod of hard rubber or ebonite is rubbed vigorously with fur it becomes endowed with the peculiar ability to pick up bits of paper and to attract small pieces of pith to itself See fig 10 1

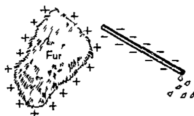


Fig 10 1 An ebonite rod which has been rubbed with fur will pick up bits of paper due to its electrical charge

Similarity between Electric and Magnetic Forces The force thus demonstrated has been called an electrical force after the Greek word for amber, the substance for which it was first observed A similar but quite different force has also been observed in connection with iron filings and the ore magnetite, or lodestone, which was used as a mariner's compass because of its directional properties See fig 10 2 This force was called a

magnetic force In each of these two cases the force was strange because unlike ordinary pushes and pulls requiring contact between *bodies* for their effects to be felt no contact was required Early physicists described such phenomena as action at a distance The force of gravity being the only other such force met with in physics the three together constitute a group which has given rise to many problems Although they all display certain common aspects they are nevertheless quite different and relate to entirely distinct phases of physics It is found as will be shown presently, that electrical and magnetic phenomena are related to each other so that it is natural to consider these together apart from the study of gravity

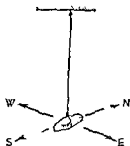


Fig 10.2 An elongated piece of magnetite or lodestone if suspended by a string will point toward the north

Two Fluid Theory of Electricity In an attempt to explain electrical phenomena it is supposed that electric forces are produced by so called *electric charges* which can be accumulated upon or wiped off from bodies when they are rubbed with other bodies as in the case of the ebonite rod rubbed with the fur It is found that an ebonite rod that has been thus rubbed with fur tends to repel another ebonite rod similarly treated but that it tends to attract toward itself a glass rod that has been rubbed with silk It is as if the charges on the ebonite and the glass were quite different—in fact opposite in character Also the fur is found to attract the ebonite and the silk to attract the glass after they have been thus rubbed together Such observations as these and a host of others gave rise to the early view that there were two distinct kinds of electric charges indicated for convenience by the names *positive* and *negative* All those substances which when rubbed with other substances behaved like the glass rod when rubbed with silk were said to be charged positively and all those behaving like the ebonite rod when rubbed with fur were said to be charged negatively The matter of which was

fundamental kinds of electricity were postulated and a very important law was discovered, namely that like charges repel and unlike charges attract each other

One-Fluid Theory Benjamin Franklin, the American statesman and scientist, feeling that this so called two fluid theory of electricity was unnecessarily complicated, proposed a view which in many ways resembles the modern viewpoint He proposed a so called single fluid theory, postulating that the positive charges represented an accumulation of charge (presumably positive) whereas the negative charge was merely a deficiency of such a positive charge Except that the modern electron theory involve charges inherently negative instead of positive, on the basis of the old classification, it explains ordinary electrostatic phenomena in a similar way, i e, by a consideration of surpluses and deficiencies of a single kind of electric charge

Electrical Terminology Based upon Positive Fluid Theory One of the difficulties encountered in the study of electricity today is that, although the negative electron theory has superseded the positive fluid theory just mentioned, much of the terminology and many electrical concepts are actually defined in terms of the positively charged fluid of Franklin Thus even the unit of electrical charge, arbitrarily defined for purposes of a logical understanding of electrical phenomena, is not the electron, because this natural unit was not discovered until about the beginning of the present century, but the so-called *unit positive charge*

Abstract Nature of the Study of Electricity This important unit is in reality only a product of the mind It is purely suppositious, but its appreciation is absolutely necessary for the proper understanding of all electrical concepts, since the science of electricity has been developed as an abstract subject Electricity unlike mechanics, for example, deals with concepts alone rather than visible things, and the student who wishes to understand a given electrical situation must, without exception, follow through a train of carefully developed logical arguments couched in precisely defined terms, because there are no revolving wheels or bouncing springs to watch here It is relatively easy to discuss academically the motion of a body under certain circumstances since bodies in motion are directly observable, and the arguments can be checked by direct observation One does not make direct observations upon electric charge, however All observations here are of

the indirect type which requires an understanding of the relationships involved, because we do not have direct sense perception in electricity Hence the physicist is particularly careful about his definitions of electrical terms

Coulomb's Law The unit positive charge, or the unit of electricity as it might be popularly called, is defined in terms of a certain law called *Coulomb's Law* Not only do like charges repel and unlike charges attract each other, but the magnitudes of these forces is found to depend upon the amounts of charge and the separation between them Coulomb's law states this in mathematical language by an expression closely resembling Newton's law of gravitation (which, it will be recalled, is a so-called inverse square law), because the force between charges diminishes as the second power of the separation The law states that the force between two charges varies directly as the product of the charges and inversely as the square of the separation In accordance with this law, *the unit of charge* is defined as that amount of electricity which, placed one centimeter away from a like amount in vacuum repels with the force of one dyne See fig 10 3

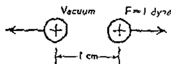


Fig 10 3 If two pointlike charges placed one centimeter apart in vacuum repel each other with a force of one dyne they each represent the electrostatic unit of charge called the stat coulomb

Since the dyne is that force which will give a gram mass an acceleration of only one centimeter per second per second, the electrostatic unit of charge just defined is a rather small quantity It is called the *stat coulomb* Incidentally it will be noted that all electrical units are named after famous physicists, but with certain prefixes attached to indicate the system to which they belong, since there are several systems of electrical units

Concept of Electric Field Thus the concept of electric charge is established as a sort of speck of electricity capable of exerting an influence upon all other such specks in its neighborhood The regions around charges are therefore places where electrical forces are manifested, such regions are usually called *electric fields*

Electric Field Intensity What is now more natural than to gauge the electrical intensity of a field if only in the mind's eye,

by the reaction of a unit positive charge? This gives rise to the important concept of *electrical field intensity* at a point It is defined as the force per unit positive charge at the point in question It is perhaps becoming clear to the student that the study of electricity, with its abstract concepts, is developed as a study of the activity and behavior of electric charges, with the unit positive charge used for exploring and testing purposes, and that the procedures involved are imagined to take place rather than directly observed

Electric Potential A common term in electrical language is *potential* One often hears references to high potential wires and the dangers associated with them Sometimes it is called high voltage What does this mean and why is voltage so important in this electrical age? What is voltage anyway?

The answers to these questions are quite definite now that the concept of the electric charge has been established Since a positive charge, for example, exerts an attractive force on a negative charge a force must be exerted to separate them If they are to be separated work must be done in the process, because work is always done when a body is displaced in the same direction as that of a force applied to it Similarly work must be done to push two charges of like sign together This is equivalent to saying that electrical potential energy is involved in the process Specifically when a positive charge is moved away from a stationary negative charge, or a negatively charged body, work must be done upon it and it is said to acquire electrical potential energy This energy is capable of moving it back toward the negative charge, if released, just as an unsupported book or other object is capable of falling to the floor, under the action of gravity In the vicinity of a positively charged body work must be done upon a positive charge, or a positively charged body, to move it from one point to another point nearer the positive charge This is described by saying that points in the vicinity of positive charges are at relatively *high potential* By the same argument it follows that points near negative charges are at *low potential* Thus the *difference in potential* between two points represents the amount of work necessary to move a unit amount of charge from the one to the other If the unit amount of charge is one stat-coulomb then the difference in potential is one *stat volt* The volt, which is 1/300th of a stat volt, has been adopted as the *practical* unit of potential In

ir discussions voltage and *potential* are terms often used mously, if not always correctly

Mechanical Analogy of Potential Difference Regarding the question of danger associated with high potential or more correctly, with large differences in potential the situation is analogous to that of a missile raised to a high elevation If after being raised it should be released energy would be liberated in an amount depending upon the mass of the missile as well as the elevation of it So with electricity a large difference in potential represents a store of electrical potential energy If it should be released by the introduction of a conducting path between the 2 points experiencing this difference in potential then energy would be liberated in an amount depending upon the magnitude of the charge and the difference in potential This is precisely what happens in a flash of lightning which is nothing but a release of electrical energy Potential difference is often referred to as electrical pressure, with which concept there is a close analogy

Electrical Conduction and Insulation. The question of how a difference in potential is maintained is an interesting one as well as an important one considering that opposite charges just naturally try to get together and resist separation Here the matter of insulation is the key to the situation All substances can be lined up in order of their ability to conduct electrical charges Those at the top end of the list are referred to as *conductors* and those at the bottom end as *insulators* The metals in general constitute the former group and substances like porcelain glass hard rubber ebonite etc constitute the latter Dry air is also a good insulator as much as 30 000 volts difference in potential can be maintained between conductors one centimeter apart in dry air

Production of Potential Differences The production of a difference in potential is a matter of separating charges This is just what happens when the ebonite rod is rubbed with fur Electrical charges are simply separated by friction the rod becoming charged negatively and the fur positively But let us now bring the story up to date lest someone ask where the charges originate to be thus capable of separation by friction i e let us consider the electron theory

The Electron Theory As was previously mentioned the unit positive charge is not a natural unit even though it may once

have been so conceived by early physicists It was an inven
designed to facilitate the study of electrical phenomena During
the first decade of the present century evidence was graduall
accumulated which disclosed the existence of a natural unit of
electric charge This view became established when the American
physicist Millikan about 1910 succeeded in isolating the electron
and measuring its charge in terms of the unit positive charge It
was found to be negative and very small, less than one-half a bil
lionth of a stat coulomb

Without going into the details of this discovery at this time
we shall treat the remainder of this description of electrica
physics in terms of the now accepted electron theory, which state
that most electrostatic phenomena are due to the existence c
free electrons associated with matter Thus it is believed toda
that when a rod of ebonite is rubbed with fur, what really hap
pens is that negative electrons are removed from the fur and a
cumulated on the rod Similarly in the case of the glass rod an
the silk, electrons are wiped off the glass and crowded on the sil
Reference is still made, however, in all quantitative discussio
to the old unit positive charge, but this is simply to be though
of as the absence of about two billion electrons Of course, the
charging of a body by friction in no way involves the generation
of charge since matter itself is made of charges Charges are not
created but merely separated by such processes Potential dif-
ferences, on the other hand, are created as charges are separated

Electric Capacity. There is still another aspect to this situ-
ation A given amount of charge does not always establish the
same potential for every body any more than a given amount of
water produces the same pressure at the base of its container
Since hydrostatic pressure at a given place depends upon the
depth of the water there, a distinction must be made between the
pressure developed by the same amount of water in two different
containers of different heights and correspondingly different cross
sections Obviously the pressure at the base of a tall slender
standpipe is greater than that at the base of a short pipe of cor-
respondingly larger diameter holding the same volume of water
See fig 10 4

On the other hand, if water is released from these two pipes
simultaneously, the pressure will drop more rapidly in the former
case The latter might be said to have more staying power Put

differently it is obvious that in the case of the second pipe more water is required to raise the pressure a given amount than in the case of the former because more water is required to raise the surface level a given amount



Fig 10 4 Although the two tanks contain the same amount of water the pressure at the base of *A* is greater than the pressure at the base of *B* Electrically tank *B* would be said to have more capacitance i e it requires more material to increase the pressure by unit amount than does tank A

Electrically a similar situation holds Conductors of large dimensions require more charge to raise the potential by a given amount than do small conductors See fig 10 5 Conductors thus have a characteristic known as *capacitance* or sometimes just called *capacity* by which term is meant not the amount of electricity that the conductor can hold but rather the amount necessary to raise the potential by a unit amount One stat-coulomb per stat volt is called a *stat farad* of capacity A conductor or a combination of conductors and insulators having capacitance or capacity is called a *condenser* Condensers consisting of layers of tin foil separated by layers of waxed paper and packed into sealed containers are widely used in all telephones radios automobiles and innumerable other electrical devices and so play a very important role in modern life

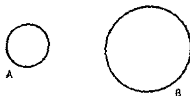


Fig 10 5 Sphere A will develop a greater potential than B with the same amount of charge owing to the larger capacitance of B

An Application of the Condenser To elaborate upon just one of these applications, consider the automobile The function of the spark plug is to produce sparks between two electrical terminals at proper intervals As has been suggested above, the spark will occur when the potential difference between the electrodes is raised to the proper value If there is a condenser in the spark plug circuit, the amount of charge required to raise the potential to the proper value is increased, with the result that when the spark does occur a greater charge and a greater amount of energy than otherwise will be released and the spark will be more intense, or hotter, as the garage man would say This may suggest the origin of the term condenser, whose function is, so to speak, to condense electricity

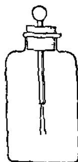


Fig 10 6 Diagram of a gold leaf electroscope enclosed in a container to shield it from air currents

Detection of Electric Charge—The Gold-Leaf Electroscope This discussion would not be complete without some mention of the manner in which electrical charges are detected The so-called gold-leaf electroscope is the instrument most commonly used for this purpose It consists simply of a narrow strip of gold foil hung over a hook suspended through the insulated stopper of a glass container in such a manner that the two ends of the foil hang down inside the glass without touching it The other end

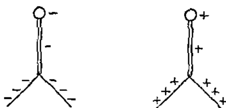


Fig 10 7 When charged either positively or negatively the gold leaves diverge

of the hook terminates in a metal ball or knob on the outer side of the stopper See fig 10 6 When a charged body is touched to the knob of the electroscope, the gold leaves diverge because they each receive the same kind of charge and are mu-

ually repelled Of course the sign of the charge cannot be directly detected because the leaves will diverge upon receiving either kind See fig 10 7

Indirectly, however, it may be possible to determine the sign of a charge, as follows If first the knob is touched with a charge of known sign, such as the positive charge on glass which has been rubbed with silk, then the leaves will remain separated with this charge upon them *Now a positively charged body brought up to* the electroscope will cause the leaves to diverge farther, but a negatively charged body will cause the leaves to collapse more or less *Thus an unknown charge can be compared with a known one*

Charging by Induction It is possible to charge an electroscope without touching it to the charged body, i e, by *induction* This is accomplished by first bringing the charged body near the knob of the electroscope, whereupon the leaves will diverge This is due to the fact that the charge attracts to the near end of the knob of the instrument charges of opposite sign and repels to the gold leaf end of the instrument an equal number of charges of the same sign, but without adding to or subtracting from the total

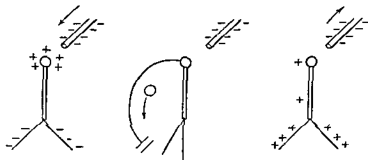


Fig 10.8 Charging an electroscope by induction The charge left on the electroscope is of opposite sign to that on the charging rod

amount of charge on the neutral electroscope By definition a neutral body has an equal number of positive and negative charges If, while the charged body is thus held near the electroscope, the latter is grounded the leaves will collapse because the ground furnishes whatever charge is needed and relieves the electroscope of the responsibility If now, after breaking the ground connections, the charged body is removed, the leaves will again diverge because the extra charge supplied by the ground

while the charged body was nearby has no place to go and is not needed either. It constitutes an extra charge on the electroscope, which has thus been charged without coming into contact with the charged body; moreover, the sign of the induced charge is the opposite of that on the original charged body. See fig. 10.8.

Summary. The concepts of charge, potential, and capacity are so closely interrelated that no satisfactory description of electrical phenomena can be given without referring to them. That is why so much attention has been devoted to them in this text. Although such attention may not seem necessary for any three particular concepts in a descriptive survey, the study of electricity is so abstract that considerable emphasis has to be laid upon the basic considerations. Otherwise the later study of electric currents and allied phenomena would be a mere display of words. With a proper basic vocabulary, on the other hand, such material as will be considered in later chapters can be very significant even if its consideration is restricted to the descriptive level. Before studying electric currents, however, it seems fitting that we should turn our attention next to a subject very closely related to electricity, namely magnetism. In the next chapter magnetic phenomena will be considered and the subject of magnetism will be developed in much the same manner as its sister subject, static electricity.

QUESTIONS

1. What is meant by the term "capacitance"?
2. What causes a small pith ball which has been attracted to a charged body to be suddenly repelled from the charged body after coming in contact with it?
3. The dangling chain formerly observed on the gasoline truck grounded the truck. Explain how this minimized the risk of fire.
4. Why is it recommended that the cleaning of silk garments in gasoline be done out of doors?
5. How may the "leaking" of charge from pointed metallic objects be explained?
6. Why is it better not to say that a positively charged object has gained positive charges, but rather to say that it has lost electrons?
7. An uncharged pith ball is suspended by a string. What happens to it when a positively charged rod is brought near it?

8 A positively charged rod is brought near a charged electroscope If the leaves collapse, what is the charge on the electroscope?
9 Is there any point in lying flat on the ground if one is caught out in the open in a severe thunderstorm? Should one stand under an isolated tree?
10 How does the mass of the nucleus of a hydrogen atom compare with that of an electron?
11 If two charged ping-pong balls repel each other, what can be said about their charges?

CHAPTER XI

MAGNETISM

Elementary Magnetic Phenomena Everyone probably has at least some knowledge of magnetism, if only a superficial one including perhaps an appreciation of the simple fact that a common horseshoe magnet will attract steel pins and iron filings but

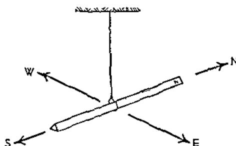


Fig 11 1 A slender bar magnet like a piece of lodestone will point north if suspended by a string as shown

will not attract anything made of brass It is also perhaps well known that a slender bar magnet suspended transversely by a thread tied around it at the center will so orient itself as to point in a north south direction See fig 11 1 This observation was made by the ancients who suspended elongated samples of the ore magnetite, commonly called lodestone, and thus the mariner's compass was invented, supposedly by the Chinese Here, as in our study of electrostatics, the question is again asked concerning the nature of these phenomena

It is also noticed that the opposite ends of a bar magnet act as though they are *magnetized oppositely* Because of the directional aspect, the terms north and south are used instead of positive and negative to designate the two ends It is also noticed that the north ends of two different magnets repel each other but that a

' end attracts a south end, just as like electric charges of ..icity repel and unlike charges attract each other

Explanations of Magnetism These phenomena suggested to early physicists that magnetism like electricity, was corpuscular in nature, involving small units of magnetism analogous to units of electric charge Such units were called *magnetic poles,* north and south, rather than positive and negative in view of the association of magnetic phenomena with geographical north and south poles A Coulomb law of attraction and repulsion of these magnetic poles was also discovered just as in the electrical case, and the *unit magnetic pole* was defined in a manner similar to that employed to define the unit charge Today, however, no special significance is attached to this unit pole not only because no such natural unit of magnetism has ever been discovered but also because it seems to be possible to explain magnetic phenomena in terms of moving electric charges making the pole concept unnecessary Nevertheless the pole concept persists in magnetic nomenclature and is still used in elementary discussions of magnetic phenomena because explanations in terms of moving charges seem to be on a somewhat advanced level

Terrestrial Magnetism The earth's magnetism provides a very interesting topic for study It appears that the earth behaves like a large spherical magnet with a north south axis which makes a relatively small angle with its geometric axis The north end of a compass needle does not point true north, i e in the direction of the north star, but toward the magnetic pole, which is situated in the general vicinity of Hudson Bay in Canada This pole of the compass is sometimes referred to as the north-seeking pole Also since the geographic and magnetic poles of the earth do not coincide it follows that compass needles which presumably point north are likely to be in error at any given point on the earth's surface In New England this error, or *angle of declination* as it is called amounts to nearly twenty degrees west

the earth are the earth, but as at a considerable depth [illegible] he fact that a compass needle suspended so as to be free to move up and down as well as from right to left tends to display a downward tendency at all points except on the magnetic equator See fig 11 2 At th poles the needle points straight up and down The ›

made with the horizontal is called the *angle of dip* and in Ne England amounts to some seventy odd degrees Thus in New En land the downward tendency outweighs the horizontal one l three to one Technically it is said that the vertical compone of the earth's magnetic field is thr times as great as the horizon component in this vicinity As the study of electrostatics, the i*tensity* of a *magne ic field* at point is attributed to the existen of a neighboring magnetic pole serves to measure the pole streng of the magnet, which to the laym is a measure of the strength of magnet in question

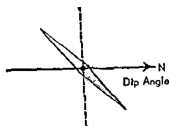


Fig 112 A compass needle mounted so as to be free to rotate in a vertical plane will dip below the horizon in the northern hemisphere

Magnetic Materials It is c tomary to associate magnetic p nomena with the substance iron This is due not only to the ea discoveries of magnetic properties among ores of iron, but a to the fact that iron is the most conspicuous of naturally occ ring magnetic substances It would be a mistake however assume that iron is the only magnetic substance Nickel a cobalt display magnetic properties and recently alloys have b made which have far exceeded iron in magnetic properties (of these alloys is known as permalloy and was developed in research laboratories of the American Telephone Company use in telephone equipment Another one of these alloys is kno as ' *alnico* "

Magnetic Induction One of the most interesting of various magnetic phenomena is *magnetic induction* When a of unmagnetized iron is brought near one end of a magnetized b magnetic poles are induced n it That is to say the bar beco magnetized by induction with the near end acquiring a pole sign opposite to that of the inducing pole and the far end acqu ing a pole of the same sign as that of the inducing pole It is a the unmagnetized bar were composed of myriads of elonga molecular magnets capable of orienting themselves at will In unmagnetized state these molecules are to be thought of as (ented at random but in the vicinity of a strong magnetic n pole let us say, all the south ends of the molecular magnets

rawn toward the north pole and the north ends are repelled rom it, causing the bar to become magnetized with equal and pposite poles This is the essence of one theory of magnetism which, although already out of date still serves to provide an ele mentary picture It does not completely clarify the nature of the molecular magnets, nor explain why only iron and a few other substances display this peculiar property to any marked degree Yet for elementary purposes it is reasonably satisfactory

Magnetic Permeability It is by induction that most magnets are made Bars of *unmagnetized iron or other magnetic substances* are subjected to strong magnetic fields which establish the mag netism by influence *so to speak One of the features of permalloy* previously mentioned is its ability to become very strongly mag netized under the *influence of a relatively weak magnetic field* This is due to a property technically called *permeability* which affords one of the most useful means of classifying magnetic sub stances If, for example *a substance is strongly magnetic its per* meability is very high and the substance is said to be *ferromag* c If, by its presence a substance enhances a magnetic field t not so strongly as a ferromagnetic substance it is called *ramagnetic* The substance bismuth on the other hand is con cuous because it weakens a magnetic field by its presence It aid to be *diamagnetic* Paramagnetic substances are character l by permeabilities greater than unity whereas a diamagnetic stance has a permeability less than unity

ummary Much *of the study of magnetism deals with elec* nagnetism which logically cannot be considered until electric *ents have been studied* Such material will be the subject for ideration in the next chapter Here we have dealt with so ed static magnetic phenomena as the previous chapter dealt static electrical phenomena Such a preliminary study de ps the vocabulary and fundamental concepts upon which the study is so dependent We shall see presently how the two s electricity and magnetism blend together in the study of ric currents

QUESTIONS

What is meant by the expression north seeking pole ?
Distinguish between *angle of declination* and *angle of dip*
What is meant by a magnetic field?

REVIEW QUESTIONS

(See page 190 for answers)

CHAPTERS VIII, IX, X, AND XI

1 That temperature on the Centigrade scale which corresponds to 68° Fahrenheit is. 1 20° C, 2 37 7° C, 3 68° C, 4 64 8° C, 5 55 5° C .....

2 The amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit is called 1 the heat of fusion, 2 the B T U, 3 the calorie, 4 the erg, 5 the heat of vaporization

3 Franklin's pulse glass demonstrates 1 specific heat; 2 the mechanical equivalence of heat and energy; 3 boiling under reduced pressure, 4 regelation, 5 surface tension

4 As the atmospheric pressure is raised the boiling temperature of a liquid is 1 lowered, 2 raised, 3 unaltered, 4 just 100° C, 5 212° F

5 The reason for nickel-plating a flatiron except on the ironing surface is 1 to prevent radiation, 2 to encourage radiation, 3 to prevent conduction, 4 to encourage conduction, 5 to encourage convection ..

6 The reason for insulating a refrigerator is 1 to prevent outward radiation, 2 to prevent heat from coming in, 3 to prevent the cold from coming out, 4 to melt the ice, 5 to prevent the ice from melting ... .

7 Cork with respect to copper is a much· 1 better radiator of heat, 2 poorer insulator of heat, 3 poorer conductor of heat, 4 poorer radiator of heat, 5 better conductor of heat . ...

8 Heat is transferred from a steam radiator to a point in a room directly beneath it largely by· 1 conduction through the air, 2 convection currents established in the air, 3 radiation through space, 4 surface tension, 5 molecular bombardment ... .

9 When an ebonite rod is rubbed with fur, 1 electrons are generated, 2 electrons are accumulated by the ebonite rod, 3 electrons are accumulated by the fur, 4 protons are acquired by the fur; 5 electricity is generated .. ..

10 When an electroscope is charged by induction· 1 its charge is always negative, 2 its charge is always positive, 3 its charge has the same sign as that of

the source 4 its charge has the opposite sign to that of the source 5 its electron content is unaltered ( )

I The leaves of a charged gold leaf electroscope stand apart 1 because the sign of the charge is the same on each leaf, 2 because the signs are opposite 3 because charges remain on the outsides of conduction bodies 4 because of electrostatic attraction 5 because electrons have the opposite sign to protons ( )

The purpose of the dangling chain on the gasoline truck is 1 to prevent positively charged protons from accumulating on the truck 2 to allow protons to leave the truck at will 3 to insure that sparking which might start a fire will take place at some distance from the gasoline 4 to warn the driver if the truck should become charged and thereby increase the fire hazard 5 to prevent an excess of deficiency of electrons from accumulating ( )

Lightning 1 never strikes the same place twice 2 never Em pire Stai l tall objects with lightning rods only if they are well grounded 5 is less hazardous to a building with lightning rods regardless of whether or not they are well grounded ( )

A compass needle points in a north south direction 1 because it is electrically charged 2 because the earth is electrically charged 3 because the earth is a magnet 4 because the magnetism of the earth is uniformly distributed 5 because north poles repel south poles ( )

CHAPTER XII

ELECTRICAL CONSIDERATIONS (*Continued*)

CURRENT ELECTRICITY

This is an electrical age and yet the number of people [who] have the ability to speak properly about electrical matte[rs is] relatively small *Part of the difficulty is undoubtedly due to* [the] exacting manner in which electrical and magnetic terms are [de]fined This has been brought out in the two preceding chapte[rs] so that the student who has followed this presentation thus [far] should find himself prepared for a descriptive consideration [of] those phenomena which make this an electrical age—an age [of] electric currents electric power, electrical devices, and all [such] topics The present chapter will deal with electric currents

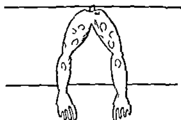


Fig 12 1 A pair of frog s legs hung from a wire was observed by Galvani to twitch as contact was accidentally made with a second wire made of d fferent material from the first wire

Galvani s Experiment T[he] Italian scientist Galvani is cr[ed]ited with being the first to h[ave] discovered the existence of c[ur]rents of electricity He is said [to] have hung a pair of frog s l[egs] from a metal wire near which [was] a second wire of different ma[te]rial connected with the first [(] fig 12 1 As the frog s legs a[cci]dentally touched the second w[ire] they were observed to twit[ch] The interpretation given to [the] phenomenon was that a dif[fer]ence in electrical potential established chemically through [the] frog s legs and the dissimilar metals caused electricity to f[low] through the circuit thus established

Flow of Charge It is clear from earlier considerations t[hat] if a conducting path is provided between two points charged [to] *different potentials electrical charge should pass from one po[int]*

to the other in an attempt to equalize the potential This would ordinarily be just a single surge of charge But if some arrangement could be provided to maintain a difference in potential between the two points while at the same time charges were passing, then a so-called current of electricity would be established This suggests, of course, a generation of potential difference at a rate great enough to offset the dissipation allowed by the conducting path The situation is entirely analogous to the flow of water out of a reservoir under a certain pressure head Unless an influx is provided to maintain the pressure head, the reservoir will eventually be drained and the flow will cease, but such an influx is made possible by the use of suitable pumps See fig 12 2

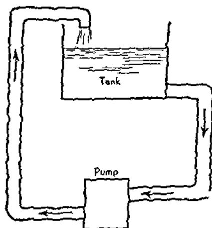
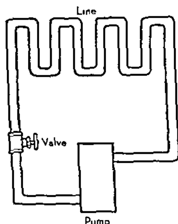


Fig 12 2 The pressure head of the tank is maintained by the pump which pumps back into the tank all the water that flows from it

The Electric Circuit It should be noted also that in addition to providing the necessary pressure, such pumps must have the ability to pump the required quantity of water if the flow is to be maintained at a constant rate Electrical batteries are such pumps for electric charges, and obviously the part they play in electrical circuits involves many factors See fig. 12 3 The study of these factors is the content of so called electric circuit considerations and includes such matters as how batteries accomplish the generation of potential differences, how electric currents



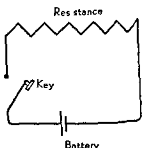


Fig 12.3 Analogy between a simple series electric circuit containing a battery, a key and a resistance element and a hydraulic circuit containing a pump, a valve and a pipe line

detected, what laws govern their existence, how resistance i offered to the flow of charge, and how electrical devices operat by means of electric currents These are just a few of the man factors that might be listed

Electromotive Force and Current There are many kind of electric pumps, or seats of electromo tive force (*E M.F*), as they are called Although the rubbing of an ebonite ro with a piece of fur may develop a ver large difference of potential between ro and fur, such a combination does not mak a good battery because it is not fa enough, i e, it cannot maintain a flo of charge of sufficient amount to be o practical importance So called chemica batteries, on the other hand, such as th common dry cell and a copper and zi electrode combination immersed in sulphu ric acid (see fig 12 4), are capable of main taining a relatively large electrical flo even though they develop a potential di ference of only a volt or so Chemical disintegration of th more active element of the battery (zinc) results in a separa

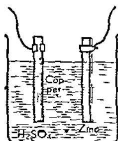


Fig 12 4 A rod of copper and a bar of zinc immersed in dilute sulphuric acid constitute an electrical battery suitable for many purposes

tion of electric charge An excess of electrons accumulates on this plate (electrode), while a corresponding deficiency occurs at the other electrode, thus producing a difference in potential between them Such cells on dead short circuit, i e, with no appreciable resistance in the circuit, can maintain a flow of many amperes for a few minutes An ampere is a flow of six and a quarter billion billion electrons per second *Electric current* is simply the rate of flow of electric charge

Electric Resistance Thus it is seen that a battery of some kind is the prime mover in every electric circuit There is another equally important factor, however, controlling the rate at which charge flows, and that is what is called *resistance* As the rate of water flow in a pipe depends upon the amount of pressure behind the water, it is also governed by the amount of resistance offered to the flow Pipes of small cross section, for example, offer greater resistance than do pipes of large cross section, and long pipes offer greater resistance than short ones Moreover, smooth-walled pipes offer less resistance than rough-walled ones These same factors also enter into electrical considerations It has already been pointed out that different substances conduct electricity differently It is also a fact that the electrical resistance of a wire depends upon its length and cross section

Ohm's Law It would be considered a mere truism to state that *the flow of fluid through a pipe depends directly upon the push behind it and inversely upon the resistance offered to it*
[illegible] *the most important law of*
[illegible] Its importance lies to no
[illegible] *ly interpreted, it explains*
practically all current phenomena and gives the physicist the means of calculating otherwise unknown quantities associated with circuits Specifically, it states that *the current intensity in a circuit* (or a portion of a circuit) *is directly proportional to the electromotive force impressed across the circuit* (or the potential drop across that portion of the circuit), *and is inversely proportional to the resistance of the circuit* (or of the portion of it under consideration) Thus it is seen that if the electromotive force impressed across a given circuit and the resistance of the circuit are known, then the current in the circuit can be readily calculated Moreover, the potential drop across a resistor can be calculated if the current and the resistance are known B[illegible]

sidering circuits as a whole and then in various parts taken rately, much information can often be determined in terms very little This is why Ohm's law is referred to as a very tant law of electric circuits

Effects of Current It is appropriate at this point that a question be raised concerning the means used for *detecting electric currents* if they are merely charges in motion, especially if charges are not capable of direct observation The answer is that electric currents are recognized by various effects which they have been found to produce To enumerate briefly, these effects are *chemical, heating,* and *magnetic* Practically all that is known about electric currents is the result of information obtained directly by studying these effects

Chemical Effect of Current That current is related t chemical activity is not to be doubted in view of the very exis ence of chemical batteries In these, the chemical reaction sepa rates charges, thereby causing negative charge to accumulate o one electrode and positive charge on the other Thus all batteri have positive and negative terminals When a closed circuit connected to these terminals, or electrodes, not only is a curre *established but its direction also is specified*

Direction of Current It is a matter of convention that the *direction of a current* is taken to be from the positive terminal of the battery to the negative, through the external circuit This is based upon the idea that unit positive charge is repelled from the positive terminal and is attracted toward the negative terminal via the conducting wire Of course, the electron theory invalidates this view since the particles which actually move through solid conductors are the negative electrons, and they pass *from the negative electrode* where the surplus exists, to the positive electrode which represents the deficiency of electrons Nevertheless, the conventional direction is still adhered to by most writers, on the grounds that it makes little difference which is actually right so long as there is common agreement, and after all it does make sense to speak of the reduction of the deficiency of electrons from the positive to the negative terminal as the electrons flow the other way

Electrolysis Metallic wires are not the only conductors of electricity Solutions of many chemical salts conduct electricity

y the formation of particles called *ions*, electrically charged either positively or negatively, which are attracted or repelled respectively from charged electrodes immersed in them Such solutions are called *electrolytes* When current is passed through an electrolyte in a cell the positive ions, called *cations*, are drawn toward the negative terminal, and the negative ions, called *anions*, are drawn toward the positive terminal These ions get their names from the terms *cathode* and *anode*, the names given to the negative and positive electrodes respectively of the electrolytic cell, the *cathode* being the terminal where current leaves the cell, and the *anode*, the one where current enters Metallic ions, being positive, are deposited out on the cathode of electrolytic cells to which they are drawn This is the basic principle of electroplating Silver may thus be electroplated on a spoon, for example, by immersing the spoon in a bath of some silver salt through which an electric current is passed if the spoon is connected to the negative terminal of the cell See fig 12 5 Faraday, about 100 years ago, studied the phenomena of electrolysis and formulated laws governing it These are considered basic to electrochemical industries even today

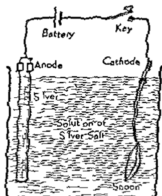


Fig 12 5 Electroplating Silver is deposited upon the spoon which is connected to the cathode of the cell when the circuit is closed

The Legal Unit of Current Electrolysis has also provided the means of specifying the unit of electric current, the *international legal ampere*, which is defined in terms of the amount of silver deposited per second out of a standard solution of silver nitrate Thus the study of the chemical effect of the electric current has yielded considerable information regarding electricity in motion, and has been responsible for the standardization of the legal unit of current

Heating Effect of Current—Joule's Law Let us next consider *the heating effect* of current It is a well-known fact that a wire carrying an electric current becomes heated Witness the modern *electric range* or electric toaster for visible evidence

of this phenomenon The conversion of electrical energy int heat energy is basic to many of the electrical devices which mak this an electrical age The fundamental principle involved is give in the law named after the English physicist Joule, who discov ered that *the rate at which heat is developed in a conductor b an electric current depends upon the second power of the curre and upon the resistance of the conductor* Thus if the current doubled the rate of heating is quadrupled Also, coils with lar resistance heat more rapidly than coils with low resistance pr viding the current is the same in each Because of the entran of the resistance factor into this picture the conclusion is su gested that Joule s law must be related to Ohm's law This found to be true both theoretically and experimentally

Electric Power As a result of this relationship still anoth important relationship is found to hold, namely that the produ of the potential drop, in volts, across a circuit such as that an electric heater or electric light, when multiplied by the cu rent, in amperes, through the circuit gives the *power*, in wat or the rate at which electrical energy is dissipated in heat T becomes a practical matter whe one is concerned with the co of electrical energy, which vari from approximately one cent t ten cents per kilowatt hour de pending upon the locality and th circumstances A *kilowatt* is on thousand watts, and a *kilowa hour* represents the amount of en ergy consumed in one hour at th rate of one kilowatt Thus at place where electrical energy cos 10 cents per kwh (kilowatt hour a *100* watt electric light bulb ca be run for 10 hours at a cost of 1 cents or one hour for one cen A flatiron probably costs several times as much to operate as th and a toaster, about the same as a flatiron

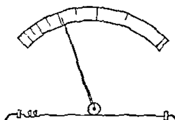


Fig 126 One method of measuring current intensity is with the hot wire ammeter The wire is wrapped around a spindle which is rotated as the wire expands owing to the heat developed in it by the current A pointer connected to the spindle swings past a graduated scale

The heating effect of current is utilized in certain types of *ammeters*, which are the instruments used for measuring curre intensity In these instruments a wire is wrapped around a spi

dle upon which is mounted a pointer See fig 12 6 As current is established in the wire, heat is developed and the wire lengthens owing to thermal expansion This causes the spindle to be rotated through a certain angle depending upon the intensity of the current, making the pointer sweep across a portion of a graduated scale placed behind it Although this principle is readily understood, it is not the one upon which most ammeters actually operate The latter utilizes the magnetic effect which will now be described

Fig 12 7 A compass needle placed on top of a horizontal wire carrying current toward the north is deflected eastward Oersted discovered this effect

Magnetic Effect of Current The Danish physicist Oersted was the first to observe that a compass needle is disturbed in the vicinity of a current-carrying wire See fig 12 7 Further examination showed the existence of a magnetic field completely encircling the current-carrying conductor This is found to be always the case, i e , no current can be established in a wire unless at the same time a magnetic field is simultaneously set up encircling the wire See fig 12 8

Thus all electric currents have magnetic fields associated with them It should be noted especially, however, that the current-carrying wire does not itself become magnetized In fact, the wire is more often than not made of copper, a nonmagnetic substance, and therefore cannot become a magnet The magnetic effect is produced in the region around the wire since the field encircles it rather than radiates out from it

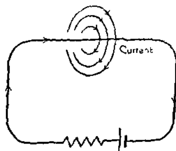


Fig 12 8 The magnetic field encircles the current carrying conductor as shown

The Electromagnet. If a wire is wound into a *long solenoidal coil*, i e , *a configuration* such as would be obtained by winding a single layer of turns *on a long* cylindrical core and then with-

by the establishment of a current in it, Faraday discovered th... the result of mechanically pushing a wire, which forms part of a closed electrical circuit, across a magnetic field is the establishment of current in the circuit as if by a battery In other words he discovered a way of inducing an electric current in a circuit merely by moving something In still other words he discovered a way of generating the electromotive force necessary to produce electric current, without the aid of batteries This simple discovery paved the way for the modern generators which, operated either by steam or water power, are the very mainstays of today's electrical civilization *Without the generators there is no elec*trical power And basic to all generators is the simple matter of electric wires being pushed across magnetic fields by the rotation of armatures The generator principle is simply the inverse of the motor principle It represents a transformation of mechanica energy into electrical energy

Lenz's Law It should be mentioned that the process described above is but one way of inducing an electric current in a circuit Further study shows that the situation is far more general than has just been described Any change whatever in th *status quo* of an electric circuit which causes a variation in th magnetic characteristics of the circuit, is sufficient to establis momentary currents in neighboring circuits This is the gist of law of induced currents known as *Lenz's Law* The inductio associated with a changing current is basic to the operation o the electrical transformer and other so called alternating-curren devices The study of these devices, however, including the spar coil, the telephone and telegraph, the radio, etc, would carry u far beyond the descriptive stage and so must be postponed for more exhaustive consideration by those students who are willin and able to develop a more mathematical language Suffice it t say that the principles discussed above are basic to the operatio of these devices and account perfectly for their behavior

Summary In this chapter the various effects of electric cur rents have been described It has been shown that the study o these effects has developed considerable information about elec tric charges in motion, although the charges themselves are no capable of being directly observed This information has alread been carefully organized into a body of logically developed law and principles during the last one hundred years or so, and toda

we live in an electrical age because of the many practical applications of these principles Of these the principles of the motor the generator are especially important

QUESTIONS

1. What is the [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. Describe the process of electroplating
6. List three major effects of the electric current
7. Distinguish between the ' direction of current and the direction of electron flow
8. Which costs more to operate a 100 watt bulb for 10 hours or a 10 watt bulb for 150 hours?
9. What was Oersted s discovery?
10. Explain how the electromagnet functions
11. What is the left hand rule?
12. How is the international ampere defined?

CHAPTER XIII

ELECTRONIC CONSIDERATIONS AND ATOMIC PHENOMENA

INTRODUCTION TO MODERN PHYSICS ELECTRICAL DISCHARGES IN GASES ELECTRONICS X RAYS RADIOACTIVITY NUCLEAR PHYSICS

The Situation about 1890 At the dawn of the twentie century the subject of physics was in a rather unique positi with reference to the other sciences and the many fields of learning This was about the end of the so-called classical period which was characterized by the Newtonian point of view The situation was unique because the physicist, in his attempt to explain physical phenomena, was apparently almost completely successful Practically all that had been observed was understandable in terms of simple concepts and laws such as Newton's laws of motion, etc These were so carefully and so logically developed that the physicist seemed to have the situation completely in hand In a fashion little short of miraculous, new observations had been fitted into places apparently made for them in the theories and hypotheses extending over a hundred or mor years On the theoretical side it was felt that physics was fas approaching the status of a dead classical subject so completel worked out in detail as to leave very little of interest, if anythin at all, for future generations to unravel All was understoo Physics was looked upon as the pride and joy of the natura philosopher, a masterpiece of logic, successful in every exper mental test At this time famous physicists made statements t the effect that all the important discoveries in physics had bee made and that most of the romance in the subject was gone, a that was left for future generations was the somewhat colorle task of extending the precision of the measurements of know physical constants and relationships

That this view was all wrong is the story of modern physic

i story that has completely revolutionized the whole outlook of physical science. That the physicist has been able to appreciate the change in the situation is even more significant In earlier chapters references have been made to the new physics, meaning the developments since 1900 or thereabouts The purpose of this chapter is the consideration of some of the ideas and concepts of modern physics as they have been developed since the discovery of the electron

Electrical Discharges in Gases About 1895 the eminent English physicist Sir J J Thomson made some strange observations that were to prove most important He was experimenting with the conduction of electricity through gases Among other things he observed that dry air at atmospheric pressure is a rather good insulator, requiring some thirty thousand volts per centimeter to break it down, i e, to make it pass charges of electricity in the form of the electric spark It was found, however, that when the pressure of the air was reduced, as by a vacuum pump for example, the necessary voltage for breakdown was appreciably diminished, but not without a very noticeable change in the character of the discharge These experiments were first carried out at a time when vacuum pumps were not only scarce but exceedingly inefficient Today however, because of technical advances, vacuum pumps are available which make it possible to perform these experiments in a demonstration lecture right before the very eyes of students

Discharge Tube Demonstration If a long, slender glass tube, say about two feet long and an inch or two in diameter, with electrodes sealed in at its closed ends, is connected to a modern vacuum pump through a tube joined to it at one side, a succession of interesting phenomena will be observed as the air is very gradually withdrawn from the tube while a large potential difference is maintained across the electrodes by a spark coil or some other source of several thousand volts *See fig 13 1* In a darkened room the experiment is enhanced At atmospheric pressure or at the start of the experiment, no discharge whatever is visible between the electrodes, but very soon after the vacuum [illegible]

becomes lighted by a purplish glow At this state the pressure

is probably not more than a few millimeters of mercury, or somewhat more than a few thousandths of atmospheric pressure

Presently, the general glow turns somewhat pinkish and then becomes quite pink In the meantime, a very definite blue glow appears near the negative electrode This is called the *negative glow* Between this glow and the main body of the pink discharge

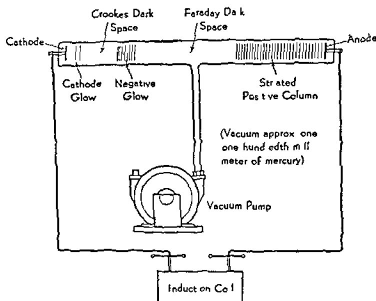


Fig 131 Discharge tube phenomena

a relatively dark space develops This is called the *Faraday dark space* The pink glow, which gradually shortens to make room for the Faraday dark space, is known as the *positive glow* or the *positive column* Soon this positive column presents a very unique appearance by breaking up into innumerable striations while at the same time the pink color fades into a pale orange color, even turning white The shortening continues as the Faraday dark space and the negative glow seem to break away from the cathode and to move nearer the positive electrode, leaving a second dark space between the negative glow and the cathode itself This dark space has become known as the *Crookes dark space* The cathode itself also glows with a violet light known as the *cathode glow*

By this time the pressure has been reduced to probably a matter of tenths or even hundredths of a millimeter of mercury As

the exhaustion continues the striations of the *positive column present* a more and more fluted appearance, becoming coarser and coarser The positive column, which is now definitely associated with the positive end of the tube, becomes shorter and shorter The Faraday dark space and negative glow move farther *and farther away from the cathode, with the result that the* Crookes dark space gets larger and larger, crowding all else right out of the positive end of the tube By the time the pressure is reduced to about a thousandth of a millimeter of mercury the whole positive column has been thus completely crowded out and the Crookes dark space completely fills the whole tube That is to say, the whole tube appears very dark except that the glass walls glow with a peculiar green light called *fluorescence* Fluorescence is the name given to the process by which radiation of a given wave length is transformed into a radiation of a different wave length (usually longer) In this case fluorescence is produced by cathode ray bombardment from the negative electrode

Cathode Rays At this stage of exhaustion it is noted that any object inside the tube between the electrodes casts a shadow on the positive end of the tube This indicates the existence of some sort of radiation from the cathode toward the anode In addition to producing fluorescence, the radiations travel in straight lines, forming sharp shadows of objects in their paths It is also found that the radiation can be focused by using a spherically concave cathode When it is thus focused upon a target, heat is generated at the spot on which the rays fall Because the radiation ema-

this text in con[illegible]

trical properties It was the discovery of these electrons by considerations of electrical discharges in gases that opened up the new era in physics

X Rays When cathode rays are allowed to fall upon a [illegible]

[illegible]

the wave variety like light and is characterized [illegible]

its ability to penetrate relatively opaque substances It not only makes possible the modern X ray shadow photographs but is used extensively today in hospitals for therapeutic work The nature of the X radiation depends upon several factors, includ-

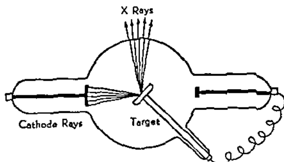


FIG 13.2 X rays may be produced by cathode rays bombarding a target

ing the potential drop across the tube, the degree of vacuum, and the substance of which the target is made

Applications of Discharge Tubes Partially exhausted tubes through which an electrical discharge is produced, as in the experiment just described, are called *Geissler tubes* The color of the discharge depends upon the gas used The modern neon advertising signs are nothing but such discharge tubes, using the gas neon, however, instead of air because of the characteristic red color of neon when activated in this manner

The blue violet light of the photographer's shop is a similar light, but one whose tube contains the substance mercury In this tube, however, a mercury arc accounts for the radiation At the present time it appears certain that ordinary household electric lights of the future will be just such discharge tubes in which the phenomenon of fluorescence is utilized by coating the walls of the tube with various chemicals capable of producing different colors Such so called fluorescent lamps are becoming quite common Incidentally, they are considerably more economical to operate than the present day filament type lamps

Thermionic Emission With the discovery of the electron came the understanding of another phenomenon which is fundamental to modern communication, i e, the *Edison effect*, or the thermionic emission of electrons Heated filaments in vacuum

tubes are found to emit electrons which can be drawn across an *empty* region by electrostatic attraction toward positively charged *plates* See fig 13 3 Such electronic behavior is the basic *principle of all* radio tubes and of the host of so called control tubes for innumerable electronic appliances See fig 13 4 The modern

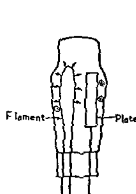


Fig 13.3 When a filament is heated in vacuum electrons are emitted by it These electrons are readily attracted to a positively charged plate producing a current between filament and plate This explains the Edison effect of a current between plate and filament when the former is charged positively

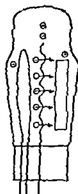


Fig 13 4 The rectifying action of the grid in a three electrode vacuum tube The grid if alternately charged positively and negatively acts so as to control the flow of electrons from filament to plate It allows the flow to take place only when it is positively charged Thus alternating currents can be rectified into direct currents

X ray tube utilizes thermionic emission for the production of electrons Once obtained by emission from a hot filament, the electrons are directed toward a target from which X rays are emitted

Photoelectric Effect Another interesting electronic phenomenon is that of the emission of electrons from the surfaces of certain substances by the action of light or radiation generally including X rays This is called the *photoelectric effect* It is basic to the operation of the photoelectric cell or electric eye as it is more popularly known When light shines upon these cells electric currents are established, but when the light is shut off the

current is interrupted See fig 13 5 Thus an electric current can be controlled just by regulating the amount of light falling upon the cell Because of this phenomenon the photoelectric cell is a very useful device for controlling electric currents It plays a very important part in the operation of sound movies and in television In the case of the former, a beam of light is varied in intensity or direction by certain markings on the side of the film, whereupon an electric current is varied accordingly to control the sound mechanism In the case of television, light reflected from the subject is picked up by a scanning device in which an electric current is varied according to the variations in intensity of the reflected light In the so called television receiving set the operations are essentially reversed and a varying current is translated into a visual image which is cast upon a screen

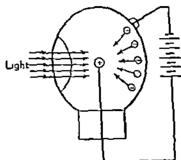


Fig 13.5 The action of a photoelectric cell Light falling upon the inside of a vacuum tube coated with certain active substances causes electrons to be emitted These electrons can be attracted to a positively charged electrode in the tube to produce an electric current capable of being controlled by variations in light intensity

Electronics Applications of principles such as those just discussed constitute the important field commonly referred to as electronics Since many of these applications lie in the field of communications, many people have acquired the erroneous idea that electronics means simply radio Of course, many war applications and developments such as radar (short-wave-directed radio) were directly concerned with radio, but probably the most important peacetime applications will be in the field of industrial controls of machinery, not to overlook the all important medical field Since the term "electronics" covers all electronic phenomena, it is actually impossible to define the field sharply in view of the fact that the electron is a basic constituent of all matter

Atomic Structure The discovery of the electron marked the beginning of an extraordinarily active era of research pertaining to the structure of the atom Before this the atom was considered to be an indivisible entity Today, however, this is

not the case Along with the discovery of cathode, or negative, rays streaming from cathode to anode, a positive radiation was also observed This positive radiation was discovered by the use of perforated cathodes which allowed particles originating at the anode to pass through the perforations in the cathode and be detected at the glass wall opposite to the anode See fig 13 6

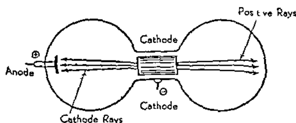


Fig 13 6 Positive rays are emitted by the anode as well as negative rays by the cathode These are positive ions Both sets of rays are capable of deflection by electric and also magnetic fields

Positive Rays Whereas the cathode rays consist of negatively charged particles, all exactly alike as shown by the action of a magnetic field upon them, the positive rays are found to consist of positively charged ions of various masses and charges The smallest of these ever observed has a mass approximately equal to that of a hydrogen atom This positive unit is called the *proton* Its charge is numerically equal to that of the electron, but its mass is some 1845 times the electronic mass It is the nucleus of the hydrogen atom The other positive ions seem to be combinations of protons and electrons, and have masses roughly corresponding to whole numbers of protons

Bohr Theory These elementary facts regarding electrical particles led to the development of a succession of theories pertaining to atomic structure Probably the most famous of these is the Bohr theory of 1913 previously mentioned in this text On this theory the hydrogen atom consists of a single proton about which a single electron revolves like the moon around the earth See fig 13 7 The atom of helium has a positively charged nucleus about which two electrons revolve In this way all the elementary atoms were thought to be made up of combinations of positive and negative charges of electricity forming dynamical systems of

varying complexity The original success of this theory was its explanation of optical spectra, about which more will follow in succeeding chapters In many details, however, this theory has been found inadequate and is no longer accepted as final Yet the views which have supplanted this theory are not altogether suitable for pictorial representation, and so the Bohr theory is still referred to in many popular discussions

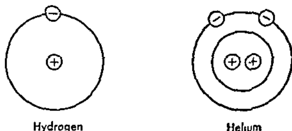


Fig 13 7 Bohr s concept of the hydrogen and the helium atom with negative electricity circulating around positively charged nuclei The helium nucleus is the alpha particle of radioactivity

For many years after the discovery of the electron and the proton, these two particles were considered the sole constituents of matter It was not until the fourth decade of the present century that this number was increased by the discovery of the neutron and then within a few months by the discovery of the positive electron The *neutron* is a particle carrying no net charge and having a mass approximately equal to that of the proton The *positive electron* (or *positron*) carries a positive charge but otherwise has all the characteristics of the negative electron It now appears that the nuclei of all atoms are composed fundamentally of protons and neutrons It is also felt today that there are probably other subatomic particles which have not yet been discovered, and, whereas only a few years ago the electron and the proton held the stage, there are now at least four recognized fundamental particles Much of today's research work is devoted to the possible discovery of additional fundamental particles and to the study of atomic nuclei Only yester day the atom was found to have a structure, and today the attention of physicists is focused upon the question of the structure of one of its component parts, namely the nucleus Tomorrow may bring yet more surprising discoveries

Radioactivity. This question of the atomic nucleus has become of additional importance today because of the discovery of artificial radioactivity *Radioactivity* is the name applied to the spontaneous disintegration of certain substances such as radium, the radiations from which were discovered by Becquerel, and the isolation of which was achieved by the researches of Madame and Pierre Curie These substances actually emit electrically charged particles along with radiation similar to X rays The radiations were named alpha, beta, and gamma before their natures were understood The *alpha* radiation consists of particles now known to be the nuclei of helium atoms Since they carry two extra positive charges they are called doubly ionized helium atoms The *beta* radiations are streams of negative electrons, and the *gamma radiation is wavelike rather than corpuscular*, being a very short-wave type of X ray See fig 13 8

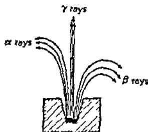


Fig 13.8 Radioactive substance in a slot in a lead block The action of a magnetic field transverse to the diagram upon α (alpha) rays β (beta) rays, and γ (gamma) rays respectively Beta rays are sharply curved one way, alpha rays are less sharply curved the other way, gamma rays are unaffected

These radiations, like X rays themselves, have been put to use in hospitals, where their therapeutic value has been recognized, but radium is very rare and very expensive Today it has been found possible to make substances artificially radioactive by bombardment with atomic particles accelerated to high velocities by super-high-voltage devices Of these the Van de Graaf high voltage generator and the Lawrence cyclotron have been widely publicized Both of these devices are capable of endowing particles such as electrons, protons, and other ions with energies equivalent to millions of electron volts The *electron volt* is the amount of energy acquired by an electron accelerated through a difference of potential of one volt These devices have really been developed for the purpose of smashing atoms and atomic nuclei to bits in order that the products of such disintegrations may be studied It is the hope of today that the disintegration of the nucleus may open up new fields of knowledge as did the breaking up of atoms a couple of generations or so ago

The Atomic Bomb Early in 1939 the remarkable discovery was made that the atom of a certain form of uranium, known as the 235 isotope, could be split by bombardment with slow neutrons into two lighter atoms, with the liberation of considerable atomic energy This process is now referred to as uranium fission The military possibilities of atomic energy were immediately recognized This led to the development of uranium fission as the war s greatest secret enterprise at a cost reputed to be around two billion dollars When a critical amount of U235 is accumulated a self sustaining nuclear reaction is a necessary consequence This takes place extremely rapidly and with the evolution of a tremendous amount of energy As a neutron splits the uranium atom, additional neutrons are evolved which split additional atoms and so on indefinitely until all the U235 is used up Another important feature of the process is the creation of a new element, plutonium, which also exhibits fission By methods which at the time of this writing are still carefully guarded military secrets, devastating atomic bombs utilizing nuclear fission were created in the summer of 1945 This marked the first occasion on which man had released sizable amounts of atomic energy, and no one can predict the social and economic consequences of this important event It took World War II to provide the stimulus for crowding into just a few years an amount of research in nuclear physics that would normally have taken probably scores of years

Summary The subject of modern physics has been developed in this chapter from the early experiments in electrical conduction through gases to the modern super high voltage machines used in nuclear disintegration experiments Although many topics have been mentioned here it must not be assumed by the student that the discussion is anything like complete *Modern physics is far too large a subject to be treated exhaustively in a* single chapter but for purposes of this descriptive survey of physics the treatment should be adequate to give the beginning student a proper orientation Much of modern physics also comes under the heading of optics and as such will be considered in succeeding chapters We turn next to a description of optical phenomena and the question of the nature of light

QUESTIONS

1 Describe briefly the appearance of the electric discharge in an elongated glass tube as the pressure of the air within is gradually reduced

2 To what, in general, does the term "electronics" refer?

3 Distinguish between cathode rays and X rays

4 How does a neutron differ from an electron or a proton?

5 What is meant by uranium fission?

CHAPTER XIV

OPTICAL CONSIDERATIONS

PHOTOMETRY LAWS OF GEOMETRIC OPTICS, OPTICAL INSTRUMENTS

Scope of Optics Of all physical phenomena there are probably none more fascinating and of more immediate interest to the average person than those related to human vision The worlds of color, sunshine, geometric design, and fine instruments also contribute to the complex realm of optics This field also includes such studies as illumination, photography, microscopy, spectroscopy, optometry, and polarization, as well as the study of certain philosophical questions such as the nature of light itself Thus it is seen that optics is indeed a very broad subject, yet at the same time, it is a part of that larger subject, physics

Complex Nature of This Study From a strictly logical point of view, this subdivision of physics is less well adapted to the methods employed in the foregoing parts of this text, i e, the logical development from one topic to another, than those which have preceded it This is not only because of the complexity of the subject but also because of the lack of any logical starting point On the historical side, many complex and apparently unrelated facts were known about optics before other simpler ones were discovered On the philosophical side, too, there has existed the perpetual controversy between the proponents of the corpuscular theory and those favoring the wave theory of the nature of light Moreover, the points of contact between this and other parts of physics are numerous, yet at the same time they are as diversified as the studies of geometry and the colors of the rainbow It is this very same difference, however, that provides us with a key to a systematic study of optical phenomena

Geometric vs Physical Optics The study naturally divides itself into two major divisions which are designated as *geometric optics* and *physical optics* The former deals with the light rays

traveling in straight lines and the images which are produced by reflection and refraction, whereas the latter deals with the physical nature of light and related phenomena We shall consider each of these in turn, starting with geometric optics partly because of the historical development of the subject The more recent researches of the last decade or so have had a particularly important bearing upon *physical optics*

Early Theories It was held by the ancients that light and vision were practically the same They thought that all light originated in the eye, for which contact was made in some mysterious way with observed objects It seems strange that they were not disturbed by the fact that objects invisible to blind people were visible to others. A later view credited so-called luminous objects with the ability to emit particles of light capable of traveling in straight lines and endowed with the property of exciting the eye of the observer That the luminous body does the emitting and the eye does the receiving is the modern view, but whether the radiation itself is corpuscular or wavelike is a matter about which physicists have argued throughout the entire history of physics

Straight-Line Propagation of Light One fact, however, has become very certain, namely that light travels in straight lines This is technically called the *rectilinear propagation* of

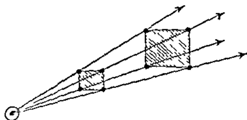


Fig 14 1 The rectilinear propagation of light

light, and is proved, in a superficial way at least, by the ability of light to cast well-defined shadows See fig 14 1 The pinhole camera also demonstrates this fact See fig 14 2 The concept of light rays is thus suggested Such *rays* either are emitted by self-luminous bodies or are reflected from illuminated bodies to be appreciated by the eye Objectively speaking, of course, the eye need not be a party to optical phenomena in general

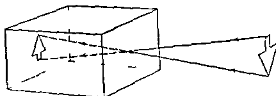


Fig 14.2 The pinhole camera demonstrates the rectilinear propagation of light

Photometry The concept of rays leads to the notion of spherical symmetry of the radiation about a point source of light and suggests a way of measuring amounts of light This is a field of optics usually referred to as *photometry* A source of light is compared with a candle and sources are rated for intensity in units called *candle power* Thus a 100 candle power source is approximately 100 times as intense as a specified type of candle A standard candle is one which emits a specified number of lumens of light where the *lumen* is a unit of light quantity If a source of light is so small that it can be thought of as a mathematical point then rules of solid geometry enable one to calculate the amounts of light emitted by sources of different candle power intensities If a luminous source is not a point but an extended surface its brightness rather than its intensity is designated *Brightness* refers to the emission of so many lumens per unit of area

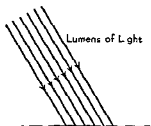


Fig 14.3 The illumination of a surface is measured by the number of lumens incident upon a unit of area One lumen per square foot is a foot-candle and is the amount of illumination received on a surface one foot away from a standard candle

Illumination When light falls upon a surface the surface is said to be illuminated See fig 14 3 The number of lumens per square foot incident upon a surface is a measure of the *illumination* and this quantity is usually expressed in foot candles The *foot candle* is the amount of light that falls upon a square foot of surface one foot away from a point source of one candle power intensity Foot candle meters have become rather common instruments today with the growth of popular interest in photography It is a foot candle meter which the photographer holds up to the light to determine the proper exposure time for a given snapshot

***Practical* Importance of Photometry** These and other *photometric* matters are of great concern today to the increasingly important profession of illuminating *engineering* *Industrialists* have become aware of the increase in efficiency of workers when proper conditions of illumination are maintained in offices and factories Instead of the one to three foot candles of illumination which prevailed in many factories in the past, proper values of five to ten foot-candles are maintained for general illumination in the modern factory For close work from ten to twenty or more foot candles are desirable The illumination of a surface exposed to full summer sunlight may run as high as 10 000 foot candles, while under full moonlight this figure may be reduced to a very small fraction of a foot candle

Law of Illumination There is a very important law of photometry known as the inverse square law This law states that the illumination of a surface by a given point source of light varies inversely as the second power of the distance between source and surface This means, for example, that if the distance between the two is doubled, the illumination is decreased to one fourth of its original value Another form of this law states that for equal illuminations due to two point sources of different intensity, the ratio of intensities is proportional to the second

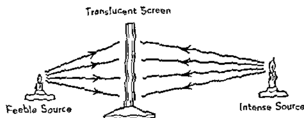


Fig 14 4 To produce the same illumination on a screen a feeble source must be much closer than an intense source The illumination produced by a point source is inversely proportional to the second power of the distance from source to screen

power of the separation meaning that for a light twice as intense as another the former must be about one and one-half times as far away as the latter to produce the same illumination at a given place See fig 14 4

Reflection In the study of geometric optics two phenomena are of the utmost importance These are *reflection* and *refraction*,

each of which is characterized by a basic relationship or natural law In the case of reflection the so called law of regular reflection states that the angle made by a reflected beam of light and a perpendicular line drawn to the reflecting surface at the point of reflection is always equal to the angle made by the incident beam and the same perpendicular line It states, moreover, that

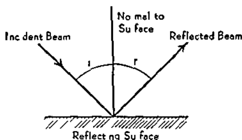


Fig 14.5 The law of regular reflection states that r = i

the reflected beam, the incident beam, and the perpendicular line just mentioned all lie in the same plane See fig 14 5

Refraction Refraction is the phenomenon by which a ray of light appears to be bent as it passes from one medium into another of different optical character because of a change in the speed of light from the one medium to the other The basic law here is *Snell s Law* This law is usually expressed in mathematical language and refers to the relative bending of light rays in two adjacent media in terms of angles and speed factors hence the reference to geometric optics again Although incapable of being precisely expressed without the use of mathematical language Snell s law states essentially that with reference to a line drawn perpendicularly to a boundary surface between two media at the point where a ray of light passes from the one to the other the ray is bent toward this perpendicular if the second medium has a greater refractive index than the first and away from it if the second medium has a smaller index By *refractive index* of a medium is meant the ratio of the velocity of light in vacuum to that in the medium Thus as a ray of light passes from air into glass or water substances in which it is slowed up, it is so bent that the angle made with the perpendicular in the glass, or the

water, is smaller than the angle made by the incident beam and the same perpendicular in air See fig 14 6 This is to say that the *angle of refraction* in glass is smaller than the *angle of incidence* in air Moreover, the angle of refraction, as thus defined, is

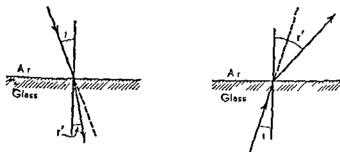


Fig 14 6 Two cases of refraction showing the bending of light as it passes from one medium to another

maller for glass than for water because the refractive index of lass is greater than that for water In Snell s law, it is specifically he trigonometric quantity known as the *sine* of each angle which nters into the formulation, although this mathematical detail eed not be emphasized in this discussion

The Phenomenon of Total Internal Reflection An intersting consequence of this law is the phenomenon of *total internal*

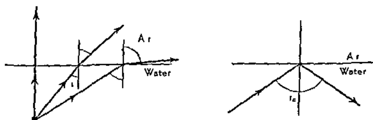


Fig 14 7 As l ght passes from water toward air a certain limiting angle incidence is encountered such that when it is exceeded all the light is tally internally reflected back into the water This angle is indicated by i_c the second diagram

incidence exceeds this *critical angle*, as it is called, the light instead of being refracted is all reflected back into the initial medium as if by a mirror, and obeys the law of reflection See fig 14 7 It is obvious that as the ray is bent away from the normal under these circumstances it cannot be bent so as to make an angle greater than 90°, hence the limit which is imposed upon the size of the initial angle of incidence For glass in air this angle is approximately 42°, which is less than the 45° of an isosceles right triangle Thus light attempting to pas through a right triangular piece o glass parallel to one side will, upo incidence at the oblique side, be re flected out of the glass in a directio parallel to the other side See fig 14 8 In other words it will b bent through 90° *as by a mirror held at 45° to the incident ray* but without the aid of any silvered material whatever The bend ing is said to be the result of total internal reflection

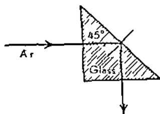


Fig 14 8 The critical angle for glass air surfaces is about 42° or less than the 45° incident angle in the diagram Therefore the light is totally internally reflected as shown

Images Formed by Plane Mirrors Considerations of th laws of reflection and refraction lead to numerous conclusions re garding the behavior of rays of light in optical media, accountin

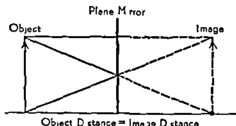
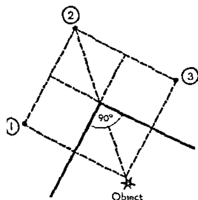


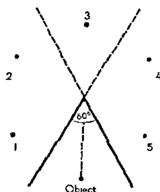
Fig 14.9 The image formed by a plane mirror is erect and vertical It is formed just as far behind the mirror as the object is in front of it

for such things as the formation of images by the use of mirror prisms and lenses Since all optical instruments depend for thei operation upon these considerations, their importance is not to b underestimated Consider the plane mirror for example It follow

from the law of reflection that a right-side-up image, formed apparently just as far behind the mirror as the object is in front of it, is accounted for See fig 14 9 This simple phenomenon is,



Three images of the object are formed by two plane mirrors making an angle of 90° if the object is placed on the line bisecting the angle between them



Five images are formed by an object placed as shown between two plane mirrors making an angle of 60° with each other

Fig 14 10 Examples of multiple images formed by reflection for plane mirrors

f course, an everyday occurrence, but nevertheless an important ne from the viewpoint of physics Other examples may easily be emonstrated See fig 14 10

Reflection from Spherical Surfaces As rays of light are flected from curved mirrors the results are even more interesting A spherical *convex* mirror always makes objects appear reuced in size, but right side up whereas a spherical *concave* irror can sometimes produce inverted images standing right ut in space, and at other times produce right-side up images cated apparently behind the mirror See fig 14 11 Such inverted iages are known technically as *real images* because they appear really exist where the rays of light are focused They can be alized upon a screen Many optical illusions are produced by al images The right-side-up images are called *virtual* images nese, however can never be ' captured on a screen

It is obvious that the formation of images by curved mirrors, lindrical as well as spherical, can be of considerable practical portance in optical instruments

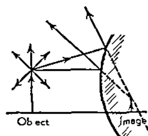


Image by a convex spherical mirror

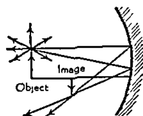
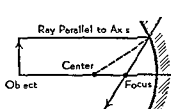


Image (one case) by a concave spherical mirror

Fig 14 11 Images by spherical mirrors

Focal Points The largest astronomical telescopes in the world such as the one on Mt Palomar in California, operate on the principle of the formation of real images of heavenly bodies by large concave mirrors One of the characteristics of these instruments is the fact that all rays of light from distant objects are brought to focus at a single point known as the *focal point* See fig 14 12 The distance from this point to the mirror is called the focal distance It can be shown that for spherical mirrors the



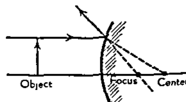


Fig 14 12 Illustrating the focal point of the concave spherical mirror and the virtual focal point of the convex spherical mirror The focal distance is one-half the radius of curvature

focal distance is just half the radius of curvature Whereas the convex spherical mirror always produces virtual images reduced in size with respect to the object, and the focal point is virtual the type and size of the image produced by the concave spherical mirror depends upon the distance between object and mirror as compared with the focal length and radius of curvature of the mirror The concave mirror is an example of a *converging system* because it actually converges light The convex mirror, on the other hand, always makes light appear to diverge and hence is called a *diverging mirror*

Simple Lenses Another example of a converging system is the double convex lens which, by refraction, causes light to be bent more at the edges than at the center and so to be converged

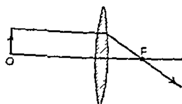


Fig 14 13 The converging lens has a real focal point toward which rays originally parallel to the axis pass after refraction

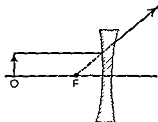


Fig 14 14 The diverging lens has a virtual focal point from which rays originally parallel to the axis appear to come after refraction

The double concave lens, on the other hand being thicker at the edge than at the center produces the opposite effect and so is an example of a diverging system See figs 14 13 and 14 14

The convergence of a system can be shown by passing a beam of sunlight restricted by an aperture, through the system if it is a lens, or by reflecting it from it if a mirror, in a smoke-filled room It will be noted that originally parallel rays (parallel because the sun is about 93 000 000 miles away and a narrow beam does not have much opportunity to spread in the short space of an ordinary room) either converge to a focus or diverge from an apparent focus as indicated See again figs 14 13 and 14 14 It

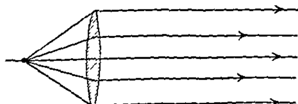


Fig 14 15 *Point source* at focus of converging lens The beam which is transmitted by the *lens is a parallel beam*

will also be noted that the rays from a small pointlike source situated on the principal axis at the focal distance away from a converging lens will be parallel upon emergence from the lens

This provides a means of producing parallel light in the laboratory without resort to sunshine See fig 14 15

With a converging system, i e, either a double convex lens or a concave mirror it is found that images of objects lying farther away than the focal length are always inverted and real For objects located within the focal distance, however, images are virtual, erect, and usually enlarged The size of the image is to the size of the object as the image distance is to the object distance

Ray Diagrams From a consideration of the laws of reflection and refraction and a knowledge of the characteristics of the focal points of a simple lens or spherical mirror it is possible to locate the image of an object by a so-called ray diagram

Ray Diagram for Concave Mirror Consider an object in the form of an arrow whose base rests on the axis of a concave spherical mirror See fig 14 16 Treating the arrow as a luminous source of light, consider first the rays of light emitted from the

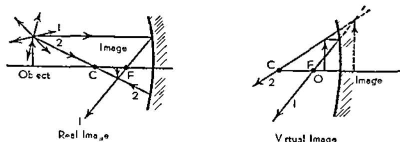


Fig 14 16 Two examples of images located by the ray diagram method These are formed by converging mirrors (concave)

head end of it Of all the rays emitted from this point there are at least two whose directions after reflection from the mirror are determinable The ray which travels parallel to the axis must be reflected through the focal point, and the ray which passes through the center of the curvature must be reflected back upon itself Except when the base of the arrow is at a distance equal to the focal length away from the mirror, these two rays will intersect in front of the mirror, or their extensions will appear to intersect behind the mirror, and such an intersection will represent an image of the point from which the rays originally emanated If the intersection takes place in front of the mirror the

image is real, if behind the mirror, then the image is virtual Now it is found that if the object lies outside the focal point the image is *always* real and inverted If, however, the object lies inside the focal point, i e, between the mirror and the focal point, the image is virtual and erect It will be recalled that when we look into a shaving mirror at very close range the observed image is right side up, behind the mirror and usually magnified If, however, the mirror is held at quite some distance, the image of the face is wrong side up, or real This is because the focal distance has been exceeded

Ray Diagram for Convex Mirror The same ray tracing procedure can be followed with the convex mirror only to discover that in this case the image is always virtual and reduced in size See fig 14 17

An interesting check on both these cases results when a third ray is considered Obviously the ray from the head end of the

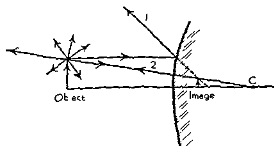


Fig 14 17 Virtual image by a diverging mirror (convex) located by ray diagram method

object which passes directly through the focus must be reflected parallel to the axis and it should also pass through the point of intersection of the other two rays

Of course it would be necessary to consider such rays as are here called first second and third for every single point of the object to reproduce every single point of the image, but this is hardly necessary since the head alone locates the position of the image when the base is on the axis

Ray Diagrams for Thin Lenses The foregoing considerations of rays is applicable also to thin lenses except that instead of being reflected the rays are transmitted through the lens and

instead of considering the ray through the center of curvature, there being no such thing for a two-sided lens, the ray passing through the actual center of the lens is used See fig 14 18 It

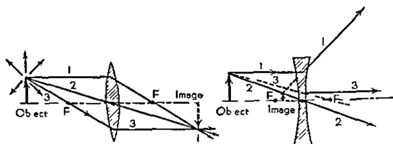


Fig 14 18 Images found by ray diagram method for converging and diverging lens These show how a third ray through the focal point emerges parallel to the axis and checks the result given by rays 1 and 2

can be shown that this ray is undeviated after passing through a thin lens By such an analysis it is found that diverging lenses always produce virtual and diminished images whereas converging lenses produce real images if the objects lie outside the focal point and virtual images if the objects lie within this distance

The Magnifying Glass A common example of the latter situation is that illustrated by the ordinary reading glass or

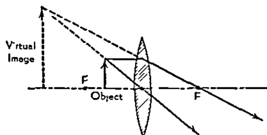


Fig 14 19 The simple microscope or ordinary magnifying glass represents a special case of image formation by a converging lens when the object is placed between the focal point and the lens The image is virtual and on the same side of the lens as the object

simple microscope as it is technically called In use, the glass is held at a distance from the printed page less than the focal length of the lens and the resulting image is right side up (virtual) and

on the same side of the lens as the object itself See fig 14 19 If the glass is held too far away from the printed page the image of the print is inverted (real) and is located out in front of the lens, i e, on the opposite side from the object.

Almost all optical instruments are combinations of mirrors and lenses, and in all cases it is possible to trace rays of light through the instruments to understand how they function Such instruments include telescopes, microscopes, opera glasses, cameras, and the all-important human eye See fig 14.20 For an optical

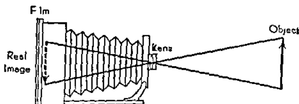


Fig 14.20 The action of the photographic camera is illustrated A real image of the object is formed on the film placed at the rear of the camera

system consisting of more than one mirror or lens it is proper, in ray diagram considerations, to first locate the image formed by the first unit of the system and then treat it as the object for the second unit, and so on in succession

The Eye. Possibly the most important optical instrument is the human eye, although the mistake must not be made of confusing the phenomenon of 'seeing' with that of the image formation by the optical system of the eye Seeing involves the interpretation by the brain of the image that is formed Here we

... and a lens arrangement serve as an optical system to produce images of outside objects These images falling on the retina, which is really the inner lining of the rear part of the eyeball, stimulate the nerve cells contained in it to send appropriate messages to the brain See fig 14 21 The whole eye is filled with water-like fluids which also take part in the refraction phenomena The aperture

or pupil, is controlled in size automatically by the action of the iris diaphragm The smaller the opening, the sharper the image that results, but too small an opening allows insufficient light to enter to stimulate the retina, and so the adjustment of the size of this opening, although performed automatically, is indeed very critical

One of the important features of the eye is the focusing arrangement Muscles are so attached to the lens that it can be flattened or bulged, with the focal length correspondingly altered

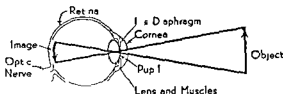
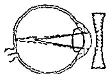


Fig 14.21 The optical system of the human eye serves to form real images on the retina the nerve tissue lining the back portion of the eyeball

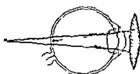
It is by this arrangement that the eye is said to be *accommodated* for objects at different distances Otherwise it would not be possible to focus the eyes first upon a distant scene and immediately thereafter upon a newspaper held at ordinary reading distance It is this power of accommodation which is gradually lost with old age, and this loss necessitates the use of so-called 'double-vision' glasses Indeed the entire question of spectacles is an application of physics in everyday life which will be considered presently

Although the whole retina is very sensitive to light, there is one spot in particular that is extremely sensitive In fact it is so sensitive that in all close work such as reading, for example, the eyeballs are continually moved so as to focus the work on these spots of the two eyes Indeed, these spots are so small that it is necessary to actually move the eyeballs to shift the attention from the one to the other of the two dots which make up the semi colon mark of punctuation Thus it is that reading makes it necessary for the eyes to be moved jerkily along the lines of the printed page, focusing upon one spot after another in rapid succession Is it any wonder that these eyes of ours sometimes get tired and require the assistance of spectacles, especially in middle life or later, for many people?

Eye Defects and Spectacles—Nearsightedness It has already been suggested that the adaptation of spectacles to assist human vision is a practical application of physics Some people are born with eyeballs too long for distinct vision Images formed by the lens system fall short of the retina, and no matter how



In myopia (nearsightedness) the image is formed before the retina With a diverging lens in front of the eye the image is formed on the retina Thus faulty vision is corrected



In hypermetropia (farsightedness) the image is formed behind the retina With a converging lens in front of this eye the image is formed on the retina

Fig 14.22 Eye defects

hard the eye attempts to accommodate distinct vision is not achieved except for very close objects This condition is popularly called nearsightedness Technically it is referred to as *myopia* The obvious remedy is the use of a diverging lens in front of the eye to increase the focal length of the whole system This is, then, why nearsighted persons wear glasses which are thicker at the edges than in the centers These are diverging glasses See fig 14 22

Farsightedness The opposite condition is of course farsightedness, or *hypermetropia*, as it is called It represents a condition in which the eyeball is too short and, as a result, images are always formed behind the retina This condition is relieved by the use of supplementary converging lenses to shorten the overall focal length of the system As people lose the power of accommodation with increasing age they generally become more and more farsighted The near point, so to speak, recedes with advancing age Thus it is that many a nearsighted person finds his vision improved as time goes on

Astigmatism Many eyes suffer from a defect known as astigmatism It is probably safe to say that more spectacles are worn for this reason than for any other Astigmatism is an aberration involving the shape of the front surface or the

the eye This defect shows up when a person attempts to see with equal distinctness all the lines of a series drawn radially from a point in a plane The astigmatic eye sees the lines in certain directions more distinctly than in others Headaches constitute a common symptom of this difficulty as a result of strain on the eye muscles when they attempt to compensate for the defect To correct a condition of astigmatism cylindrical spectacles are used with their cylindrical axes properly adjusted for the direction of the astigmatism Of course several defects can be compensated for at the same time by a pair of spectacles so that spectacle lenses are often combinations of spherical and cylindrical surfaces, representing something of an achievement on the part of the optician Indeed, it is no exaggeration to repeat that applications of physics in the aid of human vision are of the utmost importance

Summary In this chapter we have seen that geometric optics plays a very important role in the world of human experience From the ordinary spectacle lens to the largest astronomical telescope, light rays form images of luminous objects Reflection and refraction, mirrors and lenses, illumination and darkness—all are within the realm of optics, all a part of the study of physics Let us consider next the action of a prism on a beam of light, the wonders of the rainbow, and other optical phenomena related to physical optics as contrasted with geometric optics.

QUESTIONS

1 What is meant by photometry?
2 Does the intensity of illumination at a place depend upon the distance it is away from the source?
3 Define the foot-candle
4 Why can it be assumed that light passes through the center of a thin lens almost undeviated in direction?
5 Indicate the path of two rays from a point on an object which may be drawn to locate the image formed by (a) a spherical mirror, (b) a lens
6 Show by a diagram that a person can see his entire image in *a plane mirror one half* as *tall* as he is
7 How can farsightedness and nearsightedness be corrected with spectacles?
8 What type of lens must be used to produce an enlarged image on a screen?

9 Show by a diagram how light passes (a) through a lens which is thicker at the center than at the edges, (b) through a lens whose edges are thicker than the center

10 Can a double convex lens be used to start a fire? A convex mirror? A concave mirror?

11 What type of image is formed on the film of a camera by the lens?

CHAPTER XV

OPTICAL CONSIDERATIONS (*Continued*)

PHYSICAL OPTICS, DISPERSION, SPECTROSCOPY, INTERFERENCE, DIFFRACTION, POLARIZATION

In the preceding chapter, questions dealing with the directional aspects of light rays were considered It was observed that rays were reflected, bent, made to intersect one another to form images, and affected by the presence of matter The geometry of each situation was of more immediate importance than the nature of light itself In this chapter we are to be more concerned with the latter question, namely the nature of light. We shall first consider another phenomenon in which direction also plays an important part

The Visible Spectrum When a narrow beam of sunlight is passed through a triangularly shaped glass prism a very interesting and perhaps strange result is produced by refraction See fig 15 1 Not only is the ray bent, as the study of the preceding chapter would require, but it is spread out into a whole spectrum of visible colors ranging from red to violet This indicates that there is something about a beam of light which makes possible its resolution into component parts The phenomenon is referred to as *dispersion*. If the source of light is an illuminated narrow slit and an image of it is formed on a screen by a lens held near the prism, there will be reproduced on the screen successive overlapping images of the slit in every single color present in the source Thus the spectrum formed by a prism is characterized by the light source used, and many different types of spectra have been classified

Spectroscopy All incandescent light sources are found to emit continuous spectra, i e, continuous bands of light containing all the colors of the rainbow Indeed, the rainbow itself is a spectroscopic phenomenon produced by sunlight passing through droplets of water in the air when the sun makes a certain angle

with the horizon after a shower The solar spectrum, however, is not strictly a continuous spectrum, as will be pointed out presently On the other hand, electric light filaments and glowing furnaces do give spectra which are continuous

Hot vapors, like those in the modern fluorescent lamps, give rise to spectra in which only selected colors are present Again,

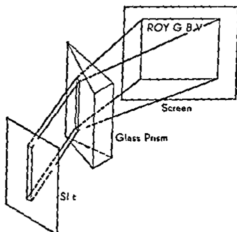


Fig 15 1 A beam of sunlight is spread out into a colored spectrum by a triangularly shaped glass prism

if the source is a slit illuminated by such a light, the spectrum will be a set of discrete lines separated by dark gaps Such a spectrum is ordinarily referred to as a *bright line* spectrum No two chemical elements yield the same bright-line spectrum, whence identification of chemical substances is possible by spectroscopic methods Indeed, new chemical elements have been discovered after spectroscopic studies have indicated their presence It was in this way that helium was discovered

The bright lines of the spectra of all chemical substances follow patterns of varying degrees of complexity which have been correlated with atomic structure Much of what is known today about atomic structure has been determined from spectroscopic studies, and the subject of spectroscopy has been one of the most fruitful subjects of research in physics in the last two decades for this reason

The third type of spectrum in this classification of spectra is the *dark-line* or *absorption* spectrum This type is produced where an incandescent source is placed in such a way with respect to a hot vapor that the light from the former is intercepted by the latter before it passes through the spectroscope Under these conditions the colors which would ordinarily constitute the spectrum from the hot vapor are absorbed from the continuous spectrum that would have been produced by the incandescent source alone This results, in the case of the slit-type spectroscope mentioned twice before, in an almost continuous spectrum, but one crossed by dark lines

Fraunhofer Lines The solar spectrum is a dark-line spectrum and indicates that the outer portions of the sun contain elements whose characteristic wave lengths have been absorbed from the otherwise continuous spectrum of the inner and hotter portions of the sun The dark lines in the solar spectrum, having first been observed by the German physicist Fraunhofer, have been called *Fraunhofer lines* The more conspicuous of these are labeled with alphabetical letters See fig 15.2 Thus the Fraunhofer D line

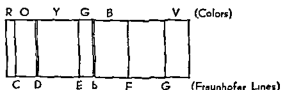


Fig 15.2 The appearance of the solar spectrum crossed by the Fraunhofer lines The colors in this spectrum are unequally spaced when formed by a prism The D line is due to sodium, the C line to hydrogen etc

refers to the sodium doublet, or the pair of very close lines in the yellow-orange region of the spectrum It occurs at precisely the same position as that occupied by a similar pair of yellow-orange lines in the spectrum of a sodium vapor lamp The so-called optical dispersion of a spectroscope is often measured by the degree to which the instrument can separate the lines in this doublet

Thus the whole question of the nature and structure of light is raised by the study of spectroscopy It is evident that so called white light, or simply sunshine, can be broken down into constituent colors by the prism of the spectroscope Moreover, it is pos-

able to recombine colors so as to reproduce white light These are simple experimental procedures which can be performed quite readily in the classroom today just as Newton demonstrated them some three hundred years ago

Color Mixtures This matter of the superposition of colors or the mixtures of colors is an interesting study in itself It is referred to by some as the physics of art It is found that only three colors, the so called primary colors, are necessary to pro duce a fairly accurate reproduction of white light, and that combinations of these three colors will reproduce practically any color Color printing utilizes three primary colors in this manner In a less accurate way, two colors sometimes produce a fairly good reproduction of white light Such pairs of colors are called complementary colors Blue and yellow, red and green, are examples of such complementary pairs

Color Addition vs Color Subtraction An important distinction must be made between the addition of two colors and the addition of two pigments, which is really the subtraction of two colors Yellow and blue light when added together produce white light, as just noted, but yellow paint applied to a blue surface pro duces a green surface Since the color of yellow paint results from the fact that all the colors but yellow, probably bordered by some green, have been absorbed, and since the color of blue paint results from the fact that all the colors except blue, probably bordered by some green are absorbed, the only color reflected by the combination is that which is reflected in common by each, namely green Thus the addition of yellow pigment to blue pigment is the subtraction of all colors except green

This distinction between addition and subtraction can be shown in another way If two spotlights, one with a yellow filter before it and the other with a blue filter, are caused to shine their light upon the same screen, the resulting spot of light on the screen will be practically white If, however, a single spotlight is used

The only color, then, that will probably get through both filters

is green Of course, a complete filtering job by the filters would produce black, or the complete absence of all color It might be noted parenthetically that no object has any color in the dark Color is the result of selective absorption of light Similarly, a red apple appears black under strictly green light because there is no red light to be reflected if the light is truly green

Interference The superposition of light not only involves the matter of additive colors but also suggests another phenomenon of considerable interest Under very special circumstances light apparently coming from two different sources can be made to produce darkness that is to say, two beams of light can be made to nullify each other Thomas Young (1773–1829) observed that when a candle is placed behind a double slit, i e, two parallel slits rather close together, the light coming from the two slits forms a peculiar pattern on a screen held in front of the slits This pattern consists of a set of alternate bright and dark bands oriented parallel to the slits When white light such as a candle source is used, the bright bands are colored, but when light of a single color is used, e g, light from a yellow sodium source, the bright bands, or fringes as they are called, are all of one color, separated of course by dark bands

The explanation of this phenomenon involves the wave theory of light Whereas water waves are known to be able to interfere with one another when they are superimposed if one is a half wave length out of phase with the other, so it follows that light waves can interfere destructively under proper circumstances The dark bands occur at those places where the distance to one slit exceeds the distance to the other slit by an integral number of half wave lengths Of course the distances between the fringes are very small since the wave length of light is very small, being of the order of several hundred thousandths of a centimeter The whole phenomenon is called interference of light The dark bands represent destructive interference and the bright bands represent constructive interference

Diffraction Although the prism spectroscope provides a means of breaking light down into its component parts, and in particular of separating white light into colors by refraction, there is still another way of producing the same effect This is by *diffraction*, which is a phenomenon of selective bending of light rays according to wave length as light passes around the edges of ob-

structions, the longer waves being bent more than the shorter ones A grating produced by ruling several thousand lines per inch on a transparent glass plate by a diamond point constitutes a device by means of which white light can be thus resolved into its colors As the light passes through this grating some of it is bent in direction, with red light bent more than blue light Consequently, spectra are produced by a fine ruled grating See fig 15 3

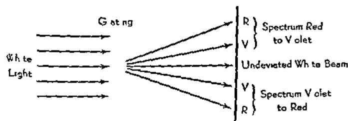


Fig 15 3 A grat ng formed by ruling several thousand lines per inch on a glass plate will produce spectra by diffraction as indicated

his is in reality an interference phenomenon and requires for its terpretation the assumption that light is a wave phenomenon or corpuscular light would not be so affected by a grating As has een noted the bending of light is selective according to wave ngth

Grating Spectroscope Furthermore this so called grating pe of spectroscope makes possible the very simple matter of easuring the wave lengths of light The bending of waves around lges is very familiar to all who have watched water waves play ound docks and piers What is not so familiar is the manner in hich the bending depends upon the length of the waves con rned Very short light waves (00004 cm to 00007 cm) are

at this phenomenon of diffraction might seem incapable of monstration except under very favorable circumstances Such wever, is not the case because inexpensive replicas of costly led gratings can be made very easily out of collodion that work actically as well as the originals themselves

Colors of Thin Films Due to Interference Another interesting phenomenon in this connection is the coloring produced by very thin films such as thin films of oil on water, or those films which constitute the so-called mother-of-pearl in oyster shells This also is an interference effect and one which can be produced only when the films are exceedingly thin The light reflected from one surface interferes with the light reflected from the other surface, re-enforcement or nullification results depending upon the number of half wave lengths included between the two surfaces Indeed, the thickness of the film can sometimes be measured by the color effects produced This is a way of utilizing light waves for measurement purposes Such interferometric methods are used in precision measurements to such extent and refinement today that it is possible to measure to a millionth of an inch with certainty Thus is made possible the interchange of working parts in the modern automobile, which have to be fitted with as little clearance as a few thousandths of an inch

Invisible Glass A very novel and interesting application of the laws of interferometry has recently been developed to make glass invisible This is accomplished by coating the glass with a film of some convenient substance The thickness of this film is a very critical matter, it is just so thick that light reflected from one side of it will interfere destructively with light reflected from the other side—(not over a quarter of a wave length of light at the most), thereby eliminating the beam that would normally be reflected from the front surface of the glass This, of course, makes the glass invisible since the line of demarcation between it and the surroundings is eliminated It is to be noted that the actual surface of a front-surfaced mirror is really invisible since the reflection is total rather than selective Camera lenses coated so as to make their surfaces invisible are found to be very effective in producing glareless photographs Similarly, invisible-glass windows in front of instruments such as clocks and electrical meters cut down the glare to observers, who can thereby see the faces of the instruments more clearly

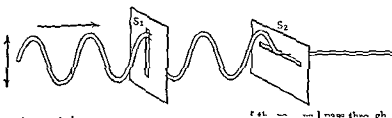
Polarized Light. As a final topic to be considered in this descriptive survey of optics, and of physics generally, we turn to polarized light, a subject which has gained considerable popularity in recent years through the advent of polaroid, the material used in certain sunglasses and in three-dimensional movies The

concepts of ınterference and dıffractıon ȷust consıdered have defi nıtely establıshed the wave aspects of lıght and yet ıt should be recalled from the quantum theory vıewpoınt that the corpuscular aspects are not to be ıgnored Nevertheless ıt must be obvıous that, for the most part the wavelıke features of lıght seem to be ınvoked more often to explaın common phenomena than the cor puscular features With thıs ın mınd the next questıon we en counter ıs whether lıght waves are longıtudınal lıke sound waves or transverse lıke elastıc waves Thıs questıon ıs best answered by the study of the polarızatıon of lıght

When a beam of lıght ıs passed through a crystal of the sub

exactly as the first one If the second dısk of polaroıd for exam ple ıs rotated through an angle of 90° wıth respect to the first one, no lıght ıs passed through ıt The phenomenon ıs called *polarızatıon. The lıght ıs saıd to be polarızed by the first dısk* whıch ıs called the *polarızer,* and ın thıs condıtıon ıts angle of polarızatıon can be determıned by the second dısk whıch ıs called the *analyzer*

Nature of Polarızed Lıght To help understand the matter better ıt ıs useful to consıder an analogy If a horızontal rope fixed at one end ıs waved up and down by the other end a transverse



wave vıbratıng ın a vertıcal plane ıs establıshed Furthermore the sıtuatıon would not be altered ıf the rope were to pass through a vertıcal slot or gate If however such a slot were turned so as to be horızontal ıt would effectıvely stop the wave motıon beyond the poınt on the rope where ıt was placed See fig 15 4 Moreover,

if two slots were used, one at some distance beyond the other, then a random sidewise motion of the free end of the rope would be restricted by the first slot to a motion parallel to itself and, unless the second slot were oriented in the same direction as the first, no wave motion would pass through the second slot There is something about the molecular or atomic arrangement in tourmaline and polaroid which restricts waves of light to a particular plane of vibration just as the slots in the above examples restrict the motion of the rope When the mode of vibration of light waves is so restricted the light is said to be plane-polarized Thus it is seen further that the polarizability of light requires that light be a transverse wave motion if it is a wave motion at all, because longitudinal waves cannot be polarized

Polarization by Reflection In addition to the phenomenon of polarization by transmission through tourmaline or polaroid, light is polarized to a large extent just by reflection alone Indeed, all reflected light is polarized somewhat, even the glare from a cement highway on a bright day Thus polaroid sunglasses are effective in reducing glare because they eliminate the polarized component of the reflected light Sky light is also polarized because all the fine particles of water vapor, dust, etc in the air reflect light Such reflection, or scattering, of short wave-length light is much more pronounced than that of long wave-length light and so the light reflected from the sky is blue Although the midday sky is blue, the sunset is reddish This is because the light from the sunset is transmitted through the earth s atmosphere and appears red because the blue has been removed by scattering The sky at noon is seen by reflected light, whereas the sunset is seen by transmitted light Both the scattered and the transmitted components are polarized

Photoelasticity. Polarized light has been found to be of considerable value to the machine designer This is because many substances which are transparent to ordinary light have quite a different appearance in polarized light Furthermore, many substances, ordinarily transparent, under polarized light become opaque when strained Glass and celluloid, for example, display regular-colored interference patterns when strained and viewed under polarized light Celluloid models of gears and other parts of machinery will show the regions of stress when viewed in operation under polarized light, and many industrial concerns carry

out such photoelastic tests on new designs before going into the production of machine parts and manufactured products In the aviation industry, in particular, where close tolerances in weight are very important, such photoelastic analyses are utilized to prevent a sacrifice in strength along with weight Indeed, the subject of polarized light is a branch of physics which illustrates quite aptly the manner in which physics has been consciously put to work by practical men who no longer are content with just engineering experience but who are quick to take advantage of every new development in the scientific laboratory

In Conclusion No wonder this is a scientific age, and no wonder laymen are interested in the intricacies of physics even if they do not, and in some cases cannot, delve deeply into the mathematics of the situation It is for students, and people generally, who are thus sincerely interested in a sober treatment of physics on the descriptive level that this text has been written It will not, and cannot, provide the necessary comprehension for the person who wishes to utilize the material in a professional way, but it is the hope of the writer that it will arouse interest and develop a sense of appreciation for physics in those who wish to make its acquaintance in a manner which one might call serious yet unprofessional

QUESTIONS

1 Sketch the passage of a ray of light through a triangular prism
2 What kind of spectrum is obtained from moonlight? from starlight?
3 Describe the appearance of a red card as it is moved through a continuous spectrum
4 Why does a mixture of all pigments produce black whereas [illegible]
5 [illegible]
6 [illegible]
7 What is meant by destructive and constructive interference of light waves?
8 [illegible] to
9 [illegible] cal methods of measurement to the physicist?

REVIEW QUESTIONS

(See page 190 for answers.)

CHAPTERS XIV AND XV

1 Light is thought to be a wave motion principally because of 1 its interference effect, 2 its enormous velocity 3 its action on the human eye 4 Einstein's theories 5 its propagation in straight lines (

2 Diffraction is 1 the same as refraction, 2 the same as fluorescence, 3 governed by the law of reflection, 4 the cause of red sunsets, 5 the bending of light around edges (

3 The age old conflict between the corpuscular and the wave theories of light has been settled by present day physicists 1 in favor of the wave view, 2 in favor of the corpuscular theory 3 by considering light to be neither wavelike nor corpuscular, 4 by a corpuscular view to explain diffraction and a wave view to explain the enormous velocity, 5 by considering light to be both wavelike and corpuscular (

4 The velocity of light was determined very precisely by 1 Newton 2 Galileo, 3 Michelson, 4 Einstein 5 Huygens (

5 The shortest plane mirror in which a man can see his entire erect image 1 is just as long as himself, 2 is dependent upon his distance away from the mirror 3 is just half his height 4 is necessarily [illegible] (

6 [illegible] brightness of a source of light, 3 solid angle 4 glare 5 illumination of a surface (

7 The illumination produced by a source of light on a surface varies 1 directly as the distance between them, 2 inversely as the distance between them, 3 inversely as the square of the distance between them, 4 directly as the square of the distance between them, 5 independently of the distance between them (

8 Light is co[illegible] partly by 1 [illegible] 4 selective absorption 5 interference (

9 When a beam of light falls obliquely on a glass surface after passing through air it is 1 bent toward

the [illegible]

10 [illegible] partially immersed in water appears 'broken" because of 1 refraction, 2 diffraction, 3 polarization, 4 interference, 5 absorption ( )

11 The spectrum of the sun 1 is an almost continuous band of colored light covering the whole visible range, 2 is a bright-line spectrum, 3 is produced only by means of a prism 4 may be produced simply by a concave mirror 5 is exactly like the spectrum of a mercury arc light ( )

12 Real images differ from virtual images in that 1 real images are always inverted, 2 real images are always erect, 3 real images are sometimes inverted but sometimes erect, 4 virtual images can be impressed on a screen, 5 only converging lenses can produce virtual images ( )

13 The wave length of yellow light is approximately 1 06 cm, 2 0006 cm, 3 00006 cm 4 006 cm, 5 0000006 cm ( )

14 Yellow light and blue light when added together produce 1 green, 2 yellow, 3 blue, 4 white, 5 black ( )

15 A double convex glass lens is 1 a diverging system, 2 capable of producing virtual images 3 unable to produce real images, 4 always free from chromatic aberration, 5 always free from spherical aberration ( )

16 The human eye is 1 essentially a spectroscope capable of analyzing the component colors in a source, 2 essentially a radio receiver permanently "tuned" *to* a narrow band of electromagnetic frequencies, 3 *in no respect whatever* a radio receiver 4 absolutely unaffected by infrared light, 5 essentially a compound microscope ( )

17 Myopia (nearsightedness) is corrected by the use of 1 concave lenses, 2 convex lenses, 3 concave mirrors 4 convex mirrors, 5 astigmatic lenses ( )

18 The largest telescopes in the world are mirrors because 1 inverted images are desired, 2 they are cheaper and more practical than lenses of the same size 3 they will gather more light than lenses of the

same size, 4 they can be made with longer focal lengths, 5 greater magnification is possible than with lenses of the same size . . . . ( )

19 Polarized light 1 was discovered by the use of polaroid, 2 indicates the corpuscular aspect of light, 3 may be used to detect strain in transparent substances; 4 is blue, 5 is of no commercial value as yet . . . . ( )

Answers to Review Questions pp 50–53

1 (1)	7 (1)	13 (1)	19 (4)	25 (1)	31 (1)
2 (1)	8 (5)	14 (3)	20 (5)	26 (3)	32 (2)
3 (4)	9 (2)	15 (3)	21 (3)	27 (3)	33 (2)
4 (1)	10 (3)	16 (3)	22 (1)	28 (1)	34 (3)
5 (2)	11 (4)	17 (4)	23 (2)	29 (4)	35 (1)
6 (5)	12 (1)	18 (3)	24 (4)	30 (3)	36 (1)
					37 (1)

Answers to Review Questions pp 89–93

1 (3)	5 (1)	10 (3)	15 (2)	20 (1)	25 (2)
2 (2)	6 (5)	11 (5)	16 (5)	21 (3)	26 (5)
3 (2)	7 (3)	12 (1)	17 (1)	22 (3)	27 (2)
4 (3)	8 (2)	13 (4)	18 (2)	23 (2)	28 (5)
	9 (4)	14 (1)	19 (1)	24 (3)	

Answers to Review Questions pp 134–135

1 (1)	3 (3)	5 (1)	8 (3)	11 (1)	13 (4)
2 (2)	4 (2)	6 (2)	9 (2)	12 (5)	14 (3)
		7 (3)	10 (4)		

Answers to Review Questions pp 188–190

1 (1)	4 (3)	7 (3)	10 (1)	13 (3)	16 (2)
2 (5)	5 (3)	8 (1)	11 (1)	14 (4)	17 (1)
3 (5)	6 (5)	9 (1)	12 (1)	15 (2)	18 (2)
					19 (3)

APPENDIX

SUPPLEMENTARY REVIEW QUESTIONS

1 The scientific method 1 is based on deductive reasoning 2 is based on inductive reasoning 3 is illustrated by the writings of Aristotle 4 has always been followed in physics 5 disregards facts ( )

2 A hypothesis is 1 the same thing as a scientific theory 2 not allowed in physics 3 never successful 4 a necessary step in inductive reasoning 5 always successful ( )

3 Force is the same as 1 mass 2 push 3 power 4 momentum 5 acceleration ( )

4 The resultant of two forces of 10 lbs each acting in opposite directions is 1 20 lbs 2 10 lbs 3 14 lbs 4 5 lbs 5 zero ( )

5 A force is always necessary 1 to keep a body moving steadily in a fixed direction 2 to change the speed of a body 3 to account for the velocity of a body 4 to keep a body at rest 5 to determine the position of a body ( )

6 Displacement is 1 the change of position 2 the same as distance traveled 3 the time rate of change of velocity 4 the same as momentum 5 synonymous with magnitude ( )

7 Velocity may change 1 in magnitude only 2 in magnitude and/or direction 3 in direction only 4 only by Newton s law 5 only horizontally ( )

8 The acceleration of gravity is 1 zero 2 32 cm per sec 3 32 ft per sec 4 32 cm per sec per sec 5 32 ft per sec per sec ( )

9 Acceleration is 1 the same as velocity 2 the same as displacement 3 the time rate of change of displacement 4 the time rate of change of velocity 5 always zero ( )

10 A body traveling in a circle with constant speed 1 has constant velocity 2 is accelerated 3 is not affected by gravity 4 has zero displacement 5 is weightless ( )

11 Newton's second law of motion proposes that 1 force is mass times acceleration, 2 weight is force, 3 a body at rest continues at rest unless a force acts, 4 to all actions there are equal and opposite reactions, 5 all bodies are attracted to the center of the earth ( )

12 Work is 1 mass times acceleration 2 force times displacement when these two quantities have the same direction, 3 force times displacement only when the two are mutually perpendicular, 4 force times velocity, 5 mass times velocity ( )

13 The work done when a 10 lb force acts horizontally on a 50 lb body on a frictionless surface is 1 10 ft-lbs, 2 10 lbs, 3 500 ft-lbs, 4 500 lbs, 5 zero ( )

14 The capacity to do work is called 1 mechanical advantage, 2 energy, 3 power, 4 efficiency, 5 momentum ( )

15 The ratio of the force overcome by a machine to the force applied to it is called 1 mechanical advantage 2 energy, 3 power, 4 efficiency, 5 work ( )

16 The maximum displacement of a vibration from equilibrium is called 1 frequency, 2 speed, 3 amplitude, 4 period 5 inertia ( )

17 Simple harmonic motion 1 takes place in a straight line, 2 is rotary 3 is torsional, 4 is always audible, 5 always involves nodes and loops ( )

18 Sound is a wave phenomenon of the following type 1 transverse, 2 circular, 3 longitudinal, 4 electro magnetic, 5 elliptical ( )

19 The velocity of a wave is 1 the product of the fre- [illegible] he fre- [illegible] times [illegible] to the next crest, 5 always 186 000 miles per second ( )

20 In a tube open at each end sound waves 1 display a node at either end, 2 display an antinode at the center, 3 resonate with a fundamental wave length of four times the tube length, 4 have a fundamental wave length of twice the tube length, 5 can never resonate ( )

21 The number of overtones in a sound 1 determines the pitch, 2 determines the quality, 3 gov-

erns the loudness, 4 accounts for all beat phenomena, 5 is always zero ( )

22 When a 256-cycle tuning fork and a 260 cycle tuning fork are sounded together, the number of beats one hears is 1 zero, 2 one, 3 two 4 three, 5 four [CAUTION! Do not confuse the answer with the number attached to the answer] ( )

23 Whenever two waves of the same frequency, speed, and amplitude traveling in opposite directions are superimposed 1 destructive interference always results 2 constructive interference always results, 3 refraction is demonstrated, 4 the phase difference is always zero, 5 standing waves are produced ( )

24 Atoms are 1 rigid spheres, 2 composed of molecules, 3 always stationary, 4 composed of electrons, protons, and neutrons, 5 nonexistent ( )

25 If the pressure of a gas is increased threefold at constant temperature the volume 1 must be increased threefold, 2 must be decreased threefold, 3 must be decreased ninefold, 4 remains the same, 5 decreases to zero ( )

26 If the temperature of a gas is raised its molecules 1 are speeded up 2 are slowed down 3 undergo no change in speed, 4 are made smaller, 5 are made larger ( )

27 The temperature on the Centigrade scale which corresponds to $-40°$ Fahrenheit is 1 $0°$ C, 2 $-22.2°$ C 3 $-72°$ C 4 $10°$ C, 5 $-40°$ C ( )

28 Boyle's law has to do with 1 liquids seeking their own level, 2 the diffusion of gases through porous substances, 3 the law of multiple proportions, 4 Magdeburg hemispheres, 5 the pressure-volume relations of a gas ( )

29 Heat is 1 a fluid, 2 energy 3 power, 4 momentum, 5 the same as temperature ( )

30 Pressure may be measured in 1 pounds, 2 inches, 3 pounds per inch, 4 pounds per square inch, ( )

31 ( )

32 The reason for insulating a refrigerator is 1 to pre-

vent outward radiation, 2 to prevent heat from coming in 3 to prevent the cold from going out, 4 to melt the ice, 5 to prevent the ice from melting ( )

33 When an ebonite rod is rubbed with fur 1 electricity is generated, 2 positive and negative electricity are separated 3 the fur is said to be negatively charged, 4 the rod is said to be positively charged, 5 nothing happens ( )

34 The proton compared with the negative electron has 1 the same sign of charge, 2 the same size, 3 the opposite sign of charge, 4 twice the charge, 5 1/1800 as much charge ( )

35 Two like electric charges 1 attract each other, 2 repel each other 3 neutralize each other 4 have no effect on each other 5 must be neutrons ( )

36 When glass is rubbed with silk 1 electricity is generated 2 the glass is positively charged 3 the glass is negatively charged 4 the silk is uncharged, 5 the silk acquires twice as much charge as the glass ( )

37 The leaves of a charged gold leaf electroscope move apart because 1 like charges attract, 2 they are [illegible] ( )

38

ite rod is rubbed with fur 1 negative electrons are taken away from the fur 2 positive electrons are accumulated on the fur, 3 protons accumulate on the rod, 4 protons are wiped off the rod, 5 the rod becomes a good conductor of electricity ( )

39 The function of a condenser is 1 to produce a spark 2 to increase potential 3 to diminish the charge, 4 to increase the intensity of a spark at a given electrical pressure, 5 to condense a given amount of charge into a smaller volume ( )

40 In a metal conductor the two ends of which are kept at a constant difference in potential 1 a current of electricity is established 2 electrons flow from positive to negative 3 protons flow from plus to minus 4 charge piles up at the negative end, 5 magnetic effects are never produced ( )

41 Electrolysis is an effect usually classified as 1 magnetic 2 heating 3 chemical 4 acoustical, 5 static ( )

42 In this locality the north end of a compass needle points 1 east of north 2 north, 3 west of north, 4 toward the north magnetic pole of the earth, 5 south ( )

43 A unit positive charge at rest and a unit north magnetic pole 1 attract each other 2 repel each other, 3 exert no effect on each other 4 produce other magnetic poles, 5 produce other electric charges ( )

44 When an electroscope is charged by induction 1 the sign of the charge induced is the same as that on the charging body, 2 the sign of the induced charge is opposite to that on the charging body 3 charges are transferred directly from the charging body to the electroscope 4 the induced charge is always positive since the leaves diverge 5 the charged electroscope has the same number of electrons before and after ( )

45 When a current is passed through a wire which crosses a magnetic field 1 the wire is attracted toward the north side of the field 2 the wire is attracted toward the south side of the field 3 the wire is not moved in any way 4 the wire always becomes magnetized 5 the wire is caused to move *at right angles to the field and at right angles to its own direction* ( )

46 Electromagnetic induction was discovered by 1 Maxwell, 2 Edison, 3 Einstein, 4 Oersted, ( )

47 ( )

48 The electric toaster depends for its operation upon which of the following effects of a current 1 the heating effect, 2 the magnetic effect 3 the chemical effect, 4 the thermoelectric effect, 5 the electrolytic effect ( )

49 Which of the following names is associated with cathode rays 1 Joule 2 Franklin, 3 Thales, 4 Oersted, 5 J J Thomson ( )

50 The following are all modern physicists except 1 Michelson 2 Compton, 3 Millikan, 4 Maxwell, 5 Heisenberg ( )

51 All of the following terms suggest modern physics

except 1 quantum theory 2 relativity 3 positron 4 proton 5 resistivity ( )

52 Light is thought to be a wave motion principally because of 1 its enormous velocity 2 its ability to be polarized 3 its propagation in straight lines 4 its action on a photographic plate 5 its ability to be focused by a lens ( )

53 A foot-candle meter is used to measure 1 illumination 2 glare 3 brightness of a source 4 candle power 5 distance ( )

54 The bending of light around edges is due to 1 refraction 2 reflection 3 polarization 4 diffraction 5 absorption ( )

55 The illumination on the flat top of a table 2 feet directly beneath a 40 candle power lamp is 1 10 foot-candles 2 10 candle power 3 20 foot candles 4 zero 5 80 foot-candles ( )

56 The visible spectrum of the sun is 1 a continuous spread of color from red to violet 2 a spread of color crossed by dark lines 3 a bright-line spectrum 4 exactly like the visible spectrum of sodium light 5 completely lacking in green light ( )

Answers to Supplementary Review Questions

1 (2)	10 (2)	19 (1)	29 (2)	39 (4)	48 (1)
2 (4)	11 (1)	20 (4)	30 (4)	40 (1)	49 (5)
3 (2)	12 (2)	21 (2)	31 (3)	41 (3)	50 (4)
4 (5)	13 (5)	22 (5)	32 (2)	42 (3)	51 (5)
5 (2)	14 (2)	23 (5)	33 (2)	43 (3)	52 (2)
6 (1)	15 (1)	24 (4)	34 (3)	44 (2)	53 (1)
7 (2)	16 (3)	25 (2)	35 (2)	45 (5)	54 (4)
8 (5)	17 (1)	26 (1)	36 (2)	46 (5)	55 (1)
9 (4)	18 (3)	27 (5)	37 (5)	47 (1)	56 (2)
		28 (5)	38 (1)		

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References to names of physicists are not included For such names, see the chapter on 'Historical Considerations pages 12–25

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